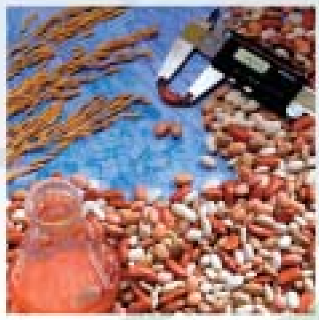
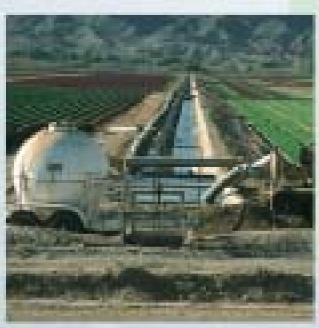
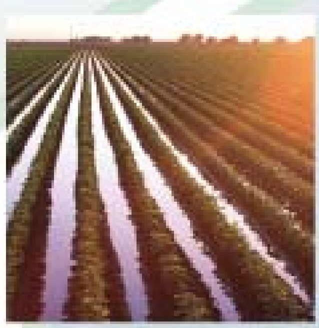
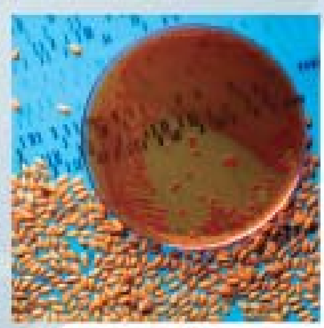
United States Department of Agriculture

21st Century Agriculture: A Critical Role for Science and Technology



June 2003

Preface

Crops that are resistant to extreme weather or plant diseases, or that can produce life-saving vaccines, medicines, and vital nutrients. Farm machinery guided by Global Positioning System satellites. New farming practices that improve air and water quality, and reduce soil erosion. Instant market information via the Internet.

The future of agriculture is not on some distant horizon; it is all around us today, with innovations emerging at a breathtaking rate.

Science and technology helped revolutionize agriculture in the 20th century in parts of the world. This report – *21st Century Agriculture: A Critical Role for Science and Technology* – highlights that transformation, and how these advances can be adapted to benefit developing countries in this century.

It showcases a broad range of conventional and emerging technologies that can increase farm productivity, enhance the nutrient content of foods, and utilize new processing and marketing strategies for crops and livestock. It also discusses advances in soil, water, nutrient, pest, and risk management, and ways to improve food safety and nutrition. And it emphasizes key issues of technology transfer, and the need for sustainable agricultural systems that can remain productive in the long run.

Many factors can help or hinder the promise of scientific progress, including research, education, economic, financial, legal, and trade institutions and policies. Science and technology, in a supportive policy environment, can drive agricultural productivity increases and economic growth to alleviate world hunger and poverty. Indeed, they may be the most important tools in achieving these vital goals.

This report was developed for the *International Ministerial Conference and Expo on Agricultural Science and Technology*, held June 23-25, 2003, in Sacramento, California. It is intended to help frame discussions on how science and technology can help meet our goals of increased agricultural productivity, enhanced food security, and stronger economic growth.

Developed and developing countries must work in partnership to strengthen global food security and reduce world hunger, and ensure access to the benefits of modern agriculture. Concerted international efforts that facilitate the adoption of scientific and technological advances will help expand market opportunities and ensure that all countries have the capacity to participate in the global economy.

Ann M. Veneman
Secretary, U.S. Department of Agriculture

United States Department of Agriculture

June 2003

21st Century Agriculture:

A Critical Role for Science and Technology

Executive Summary

If countries have policy, regulatory, and institutional frameworks in place to support science and technology, they can increase agricultural productivity and stimulate economic growth.

Advances in science and technology contributed to substantial gains in global agricultural productivity in the 20th century. Not all regions benefited equally, however, and it remains a challenge in the 21st century to ensure that all countries have access to innovations and discoveries that could raise incomes, reduce hunger, and improve nutrition. If countries have policy, regulatory, and institutional frameworks in place to support science and technology, they can increase agricultural productivity and stimulate economic growth. Thus, chronic hunger would be reduced, and opportunities to participate in global markets would increase.

Agricultural production technologies and practices have been developed to improve soil, water, nutrient, and pest management. Crop improvements contributed to the successes of the Green Revolution. Modern biotechnology tools have been used to achieve higher levels of stability and sustainability in crop production. These innovations have increased yields and reduced environmental impacts. Advances in animal breeding and health have increased both the quantity and quality of animal protein available to consumers.

Improvements in marketing, processing, and transportation technologies have expanded the choices of food that are readily available to consumers. These innovations can be adapted to preserve and deliver vitamin-rich foods to help combat nutrient deficiencies in all countries. In addition, technologies to reduce food safety hazards can be used to increase the health of both rural and urban populations.

Scientific and technological advances in the 21st century will result from research investments in both traditional agricultural fields and other emerging disciplines. Agricultural production research will be targeted to develop crops and animals that can tolerate a wider range of environmental conditions and offer consumers desired characteristics. Molecular methods will be used to diagnose diseases, locate pollutants in the environment, and detect harmful micro-organisms in food. Modern biotechnology holds promise for the production of pharmaceutical compounds such as vaccines within locally grown plants. Innovations in biological and information sciences have resulted in several emerging fields that hold promise for the development of future agricultural technologies. The new fields of bioremediation, nanotechnology, genomics, and bioinformatics will increase knowledge that can be shared and used to improve sustainable agricultural production and protect ecosystem functions in developed and developing countries alike.

These advances hold great promise, but the full benefits of scientific breakthroughs will not be realized without the dissemination and adoption of new technologies. In each country, the successful local development of technologies or the transfer and adaptation of innovations from others will depend on incentives and barriers faced by investors and producers. Countries with strong research, health, and education capacity will offer a supportive environment for technology development and investment.

Countries have many crucial decisions to make in meeting their sustainable agricultural goals. These decisions need to be made and implemented based on decisionmakers' knowledge of their countries' unique environmental, social, and economic characteristics. There are many ways that developed countries, international institutions, and businesses can increase the possibilities for all countries to benefit from scientific and technological advances.

Introduction

Scientific breakthroughs and technological innovations in the 20th century fueled substantial gains in agricultural productivity in many countries. The development of new technologies and practices resulted from both public and private investments in research. Countries that enjoyed high agricultural productivity growth were able to increase incomes, participate in global markets, reduce hunger, and improve the quality of life of their citizens. For the countries that were not able to benefit from the advances in science and technology, agricultural productivity did not grow quickly. This resulted in unmet needs for income growth and food security—defined as access by all people at all times to sufficient nutritious food for active, healthy lives.

With supportive policy, regulatory, and institutional frameworks in place, science and technology can increase agricultural productivity and stimulate economic growth in all countries, thus reducing chronic hunger and offering more opportunities for participation in global markets.

Expanded global trade, investment, and economic integration could expand market opportunities for developing and developed economies alike. The potential benefits of international trade and technological progress are enormous. Integrated capital markets and the free flow of information create opportunities for growth and can have a significant impact on reducing poverty and hunger.

Industrialized nations, including the United States, have made a commitment to increase the opportunities for all countries to participate in the global economy. One way is to help developing countries strengthen their capacity to conduct research, develop regulations, and create the economic and institutional environment to facilitate the transfer of science and technologies appropriate to each country's unique needs. Investments made

through public/private partnerships and between countries can have a great long-term payoff for all participants.

Section I of this report, "Agricultural Productivity: An Engine of Development," describes how scientific and technological investments have resulted in agricultural productivity gains for developed countries, and for those developing countries that benefited most from the Green Revolution that began in the last half of the 20th century.

Many technologies and practices developed in the 20th century, and those that will be developed in the 21st century, could be adapted to meet the unique needs of each developing country. Scientific understanding about the interactions between agricultural production and ecosystem health can also contribute to the development of a sustainable agricultural system. The choice of an appropriate set of technologies and practices should incorporate indigenous knowledge of the local economic, social, and natural resource environment. Section II, "Potential Benefits of Science and Technology," describes these production and postharvest technologies, along with promising new scientific fields that may lead to innovations in the future.

The development and transfer of science and agricultural technologies will be most successful if current impediments and barriers are reduced. Lack of infrastructure, poor natural resource endowments, and restrictive international policies can all hinder technology development, transfer, and adaptation. These impediments can also hinder farmers from adopting sustainable agricultural practices. Section III, "Support for Technology Development and Transfer," discusses economic, financial, and policy infrastructure and presents examples of barriers to the development and transfer of the newest science, such as intellectual property rights restrictions. It also includes examples of public and private partnerships that can increase the capacity of developing countries to create and implement a science and technology program consistent with their sustainable agricultural goals and based on their unique environmental, social, and economic conditions. When countries can make choices based on sound science and accurate information, the chances of attaining their individual national goals are high.

The challenges and opportunities for increasing sustainable agricultural productivity are described in Section IV. Public and private partnerships can increase the possibilities for countries to have access to scientific and technological advances. Indigenous development of technologies and transfer of innovations will be enhanced when barriers to investment are lowered.

Expanded global trade, investment, and economic integration could expand market opportunities for developing and developed economies alike. The potential benefits of international trade and technological progress are enormous.

I

Agricultural Productivity: An Engine of Development

Agricultural productivity *measures the amount of agricultural output produced with a given level of inputs. Agricultural productivity can be defined and measured in a variety of ways, including the amount of a single output per unit of a single input (e.g., tons of wheat per hectare of land or per worker), or in terms of an index of multiple outputs divided by an index of multiple inputs (e.g., the value of all farm outputs divided by the value of all farm inputs).*

Science and Technology Contribute to Productivity

Technological advancement, broadly defined as any positive change in the way goods and services are produced, has been recognized by economists as a critical contributor to economic growth. Research is necessary to innovate, but product development and testing are needed before commercialization or transfer of technology can occur. Producers need good market and policy incentives to adopt new technologies, and the skills to use them effectively. These basic components of technology development and dissemination are the same in developed and developing countries.

R&D increases productivity

New technologies and innovative practices have been key factors in the economic development of high-income countries. Investments in agricultural research and development (R&D) by both the private and public sectors have resulted in a high level of productivity. The production of more agricultural goods using fewer inputs frees resources to be invested in other parts of a country's economy, thus increasing affluence. Productivity increases occurred because of innovations in machinery, pesticides, fertilizers, information technologies, and plant breeding. While there has been a focus on production improvements for

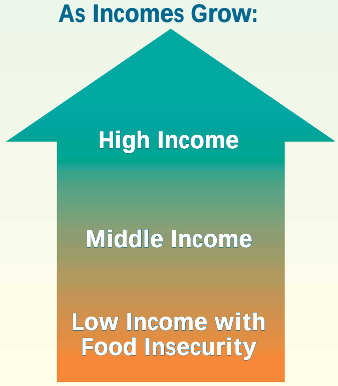
Research Priorites To Meet Consumers' Needs

Consumer demands depend in part on income level, and public and private research priorities change to meet those demands. To supply the products demanded in high-income countries, the private sector invests in research to develop value-added products that can be profitably traded. Public-sector agricultural research can develop technologies and practices used to ensure food safety and to lessen potential environmental impacts of production. If consumer demand is strong for products that meet food safety or environmental quality criteria, the private sector can provide these products profitably as well. In developing countries, the public sector may need to enhance its science and regulatory infrastructure to ensure a safe food supply and a protected environment.

To meet demands in middle-income countries, both public and private agricultural research programs focus on providing increased quantities of affordable sources of nutrition. There is less demand for value-added and processed products than in high-income countries.

In less-developed countries, demand for imported products is low. R&D efforts within many of these countries are not sufficient to substantially increase agricultural productivity, and opportunities for profitable private research investment are limited. The success of public research depends on financial resources and educational levels (human capital), as well as on natural resource endowments, adequate infrastructure, and political stability, among many factors. Due to constraints on many of these enabling factors, less developed countries often do not have the strong indigenous public research capacity needed to develop technologies suited to their needs.

As Incomes Grow: **Research Priorities Change**



Private Research—focuses on varied, fresh, convenient foods.
Public Research—focuses on food safety and improved environmental quality.

Private and Public Research—focuses on high nutrition and increased production efficiency.

Public Research—focuses on productivity of local staple products.

farmers, consumers also benefit from the increased production of basic commodities at low prices. Innovations in food storage, processing, packaging, transportation, and increasing shelf life resulted in a wide variety of high-quality products being available year round. Recent breakthroughs in information technology and life sciences have expanded opportunities to increase production efficiency and to provide consumers with the safe, affordable, nutritious products they demand.

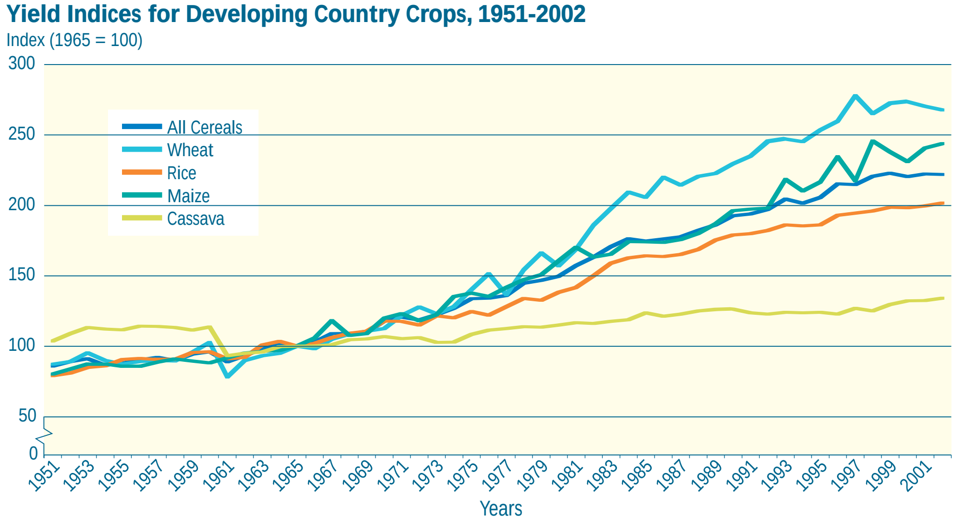
Consumers are increasingly concerned with the safety, variety, and nutritional value of food products. In addition, the public demands that agricultural production practices protect the environment and conserve natural resources. Some agricultural practices have had detrimental effects on human health and the environment. Public research efforts have developed technologies and practices that have reduced these negative effects, and it is that set of technologies from which countries choose when trying to achieve their sustainable agricultural goals.

The Green Revolution

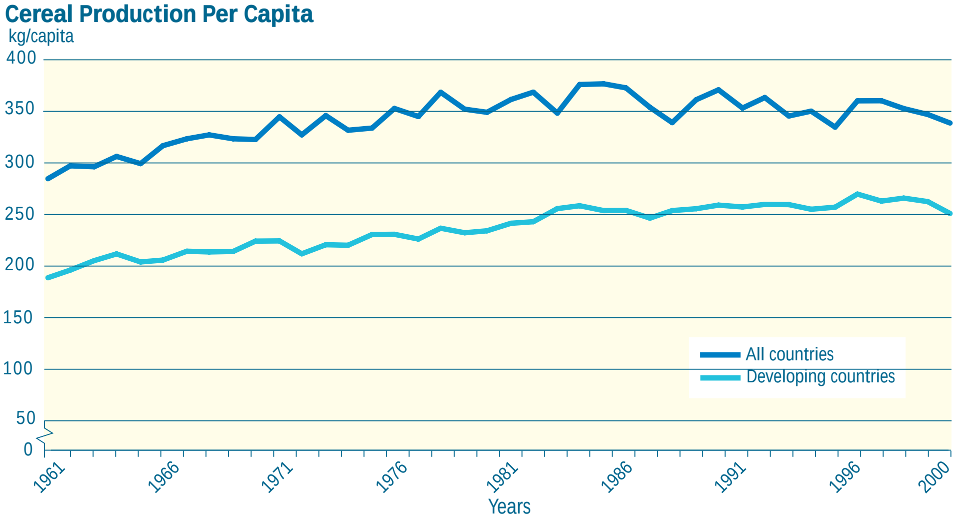
The dramatic breakthrough in agricultural research in industrial countries, exemplified by yield gains and increases in agricultural productivity, took many years to reach some developing countries and bypassed others altogether. Before the 1960s, in developing countries, relatively little was invested in agricultural research, particularly for food crops. At that time, the Rockefeller and Ford Foundations helped establish an international agricultural research system to serve the research needs of developing countries.

The first efforts were in public research for rice, wheat, and maize. By the late 1960s, the development and spread of high-yielding varieties of these crops, combined with greater use of fertilizers and irrigation, led to notable increases in crop yields that greatly expanded the scope of the Green Revolution. This accomplishment reduced the incidence of famines, particularly in densely populated

Yield Indices for Developing Country Crops, 1951-2002



Cereal Production Per Capita



…the development and spread of high-yielding varieties of [rice, wheat, and maize], combined with greater use of fertilizers and irrigation, led to notable increases in crop yields that greatly expanded the scope of the Green Revolution. This accomplishment reduced the incidence of famines….

In both developing and developed countries, the farmers who can absorb the risks associated with trying new agricultural technologies due to their access to credit or larger holdings often adopt first.

countries in Asia. High-yielding varieties were developed by philanthropic or public research institutions and then given away or sold at low prices.

Yield growth for various crops in developing regions has been substantial during the past three decades. For example, since 1965, wheat, rice, and maize yields in developing countries have more than doubled. The contributions made by agricultural R&D to increasing food production, however, extend beyond yield increases alone. One of the major contributions of rice genetic improvement has been the development of varieties that produce yields similar to those of older rice varieties, but in shorter periods of time and with less loss of grain. This has enabled double or even triple cropping in areas that previously produced only one or two crops per year. For other staple crops such as cassava, yield gains have been relatively modest.

The net result of this R&D-driven technological transformation has been an increase in per capita food production in developing countries taken in the aggregate. From 1960 to 2000, for example, developing countries' population grew by around 125 percent, while the production of cereal in these countries tripled. Over the same period, agricultural land in developing countries increased by only about 25 percent. Thus, increased yields per hectare, not the expansion of agricultural land, played the dominant role in expanding cereal production. In some regions, however, the expansion of agricultural land resulted in the loss of some ecological assets, but conservation efforts

Summary of nearly 400 studies of the economic rate of return to agricultural R&D

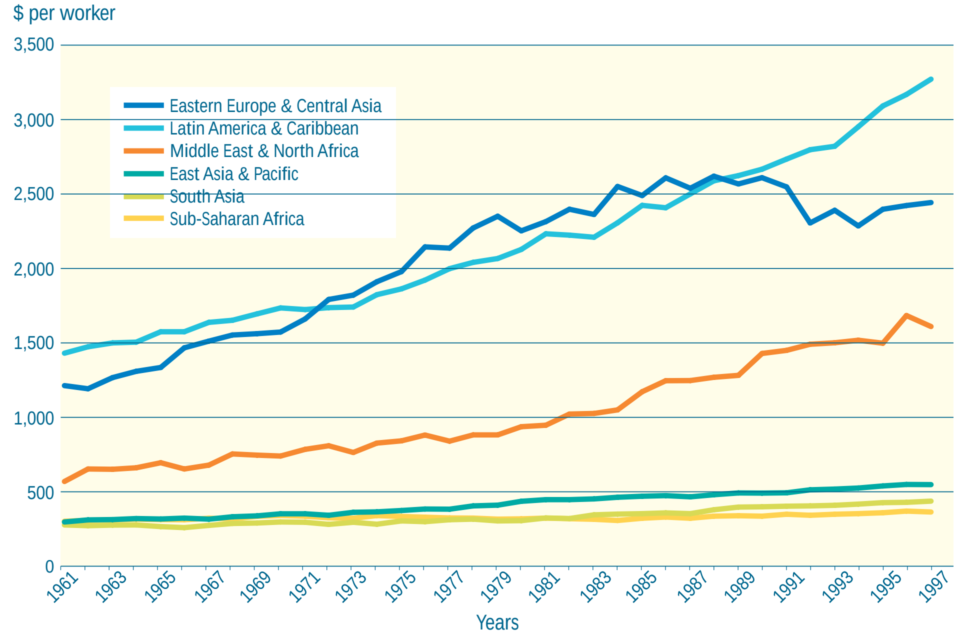
Region	Number of studies	Economic rate of return (median percent)
Asia	120	~ 55
Latin America	80	~ 40
Africa	44	~ 35
All developing	244	~ 50
Organization for Economic Cooperation and Development (OECD)	146	~ 45

Source: R.E. Evenson; Handbook of Agricultural Economics

Not all countries have benefited from agricultural innovations.

Labor productivity in developed countries was $5,400 per worker in 1961 and $25,000 in 1997.

Labor Productivity
$ per worker



have been successful in slowing those losses in other areas. India was able to increase conservation efforts and actually expand its forests and woodlands by 21 percent between 1963 and 1999.

Economic studies have indicated that the rates of return to investment in agricultural R&D tend to be high in both developing and developed countries. Developing countries have made many impressive, scientifically based gains in food production over the past 40 years. However, these successes have not been universal.

Yield gains have been distributed unevenly among food crops that are important in developing countries. Much of the Green Revolution crop research resulted in advancements in wheat and rice production. Some maize/corn improvements were made that benefited part of Africa, but research did not focus on Africa's primary staple crops: yams, cassava, sorghum, and cowpeas. Though yields for root crops like cassava have risen slowly since the 1960s, the rate of increase in yield has been much lower for these crops than it has been for cereals.

Studies have shown that although small farmers lagged behind large farmers in adopting Green Revolution technologies, in many cases they eventually did benefit from the use of these innovations. In both developing and developed countries, the farmers who can absorb the risks associated with trying new agricultural technologies due to their access to credit or larger holdings often adopt first. Their success serves as a model for those farmers who were initially uncertain about the new technology.

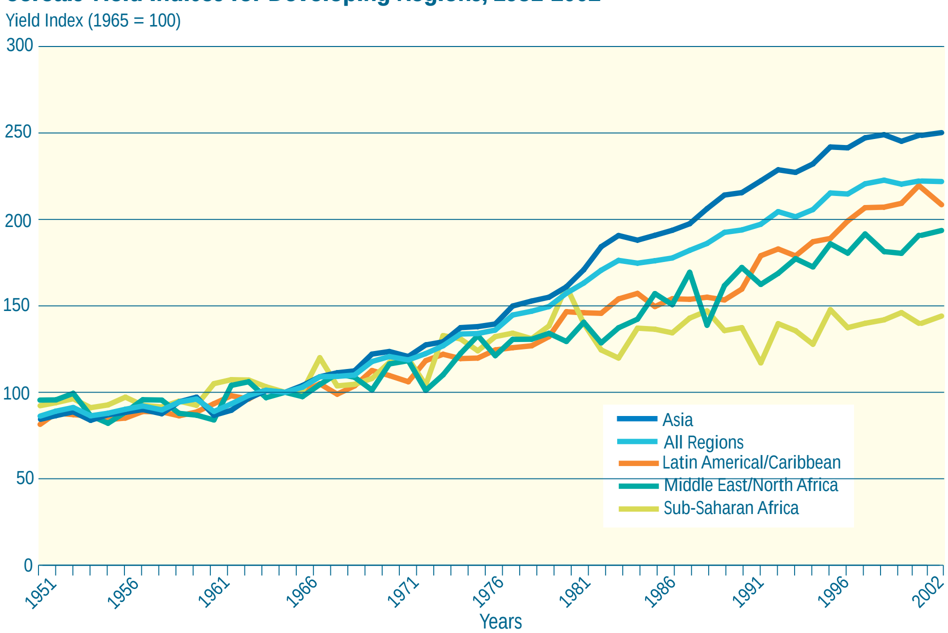
Despite the many benefits to developing countries that resulted from the Green Revolution, there were some negative environmental impacts. To effectively grow high-yielding crop varieties, fertilizers, pesticides, and water often were needed. Chemical residues were transported into waterways in tropical regions, and built up in soils in arid areas. Some chemicals leached into ground water. The use of synthetic pesticides had impacts on farm family health, and reduced the natural enemies of some targeted pests. These negative effects were experienced at the same time in developed countries, which led to research on technologies and practices to avoid the problems in the future.

Unmet Needs for Food Security and Income Growth

Many developing countries have a great need for increased productivity growth. Population growth rates in lower income countries are generally higher than in developed regions. If current trends continue, the world's population is expected to increase by 737 million people by 2011, and most of the growth will be in developing countries. Unfortunately, crop yields are often substantially lower in these developing regions. Even though world food production has been increasing faster than population growth, many people are undernourished in less developed regions. In Sub-Saharan Africa, 43 percent of the population is chronically undernourished, consuming less than the minimum recommended nutritional requirements. However, the greatest numbers of undernourished people live in Asia, which is the most highly populated region.

With high population and low productivity levels, many low-income countries are not able to produce enough food domestically to meet basic nutrition needs. Nor do they have adequate income to

Cereals Yield Indices for Developing Regions, 1951-2002



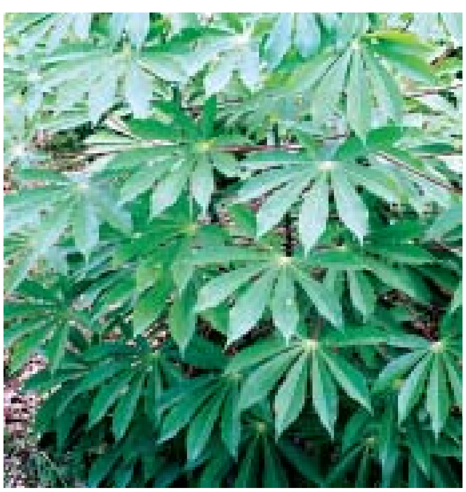
Food security *is defined as access by all people at all times to sufficient food for active, healthy lives. As such, food security depends not only on how much food is available, but also on the access that people have to food–whether by purchasing it or by producing it themselves. Access depends in turn on economic variables such as food prices and household incomes, as well as on agricultural technology and the quantity and quality of natural resources.*

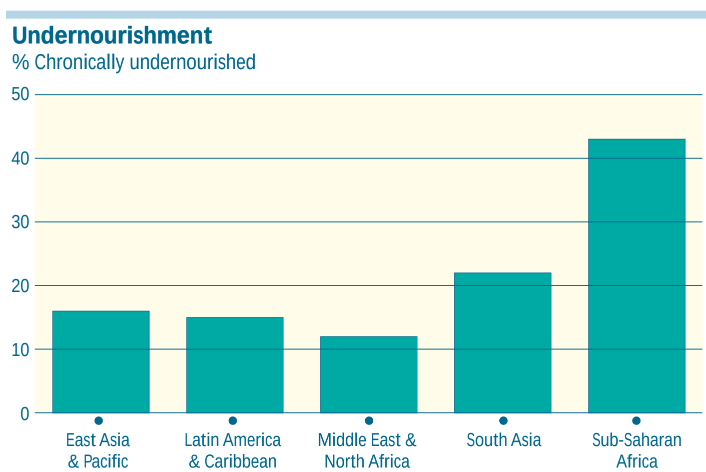
Given that 90 percent of the food consumed in many developing countries is produced locally, production increases and product diversification could improve the health and well-being of the poor.

import enough to eliminate these food gaps. Agricultural productivity in developing countries must grow more rapidly than it has in the past decade, both to meet increasing demands for food and to raise rural and urban incomes—which, in turn, will lead to the possibility of increased agricultural trade and earning foreign exchange. For example, since 1980, farm worker productivity rose by nearly 50 percent in Thailand, nearly doubled in China, and more than tripled in South Korea. These increases had significant effects on Asia's economies by stimulating growth, reducing poverty and malnutrition, and helping to keep food prices down. The development and adoption of new technologies will be necessary to increase both food supplies and access to food.

Food-insecure countries with low incomes, reliance on local staple crops, and limited trade opportunities have benefited less than other developing countries from R&D-based advances in food production. Many of the most significant advances in agricultural technology were made in developed countries where greater resources were devoted to agricultural R&D. Although food-insecure countries can be found in all major developing regions, they are particularly concentrated in Sub-Saharan Africa. In the lowest income countries, about one-third of food consumption comes from noncereal commodities such as cassava, for which there have been limited research investments and few technological breakthroughs. In much of Sub-Saharan Africa, per capita food production has declined in the last two decades, a period in which public sector investment in agricultural R&D stagnated in this region.

The World Bank estimates that 75 percent of the very poor, or nearly 1 billion people, live and work in rural areas and depend on agriculture for their livelihoods, either directly or indirectly. Given that 90 percent of the food consumed in many developing countries is produced locally, production increases and product diversification could improve the health and well-being of the poor. Food security is the foundation for social security.

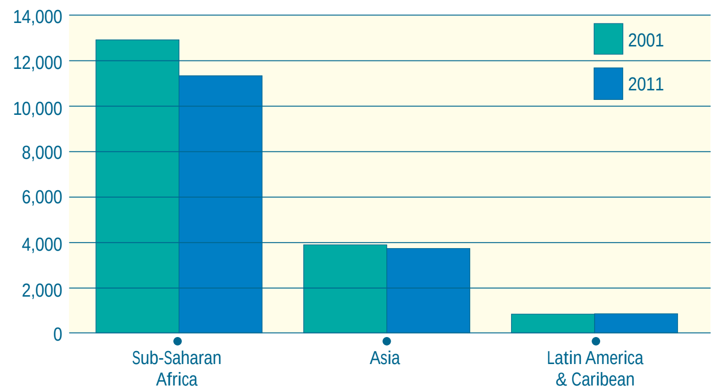




Undernourishment is a severe problem in several regions.

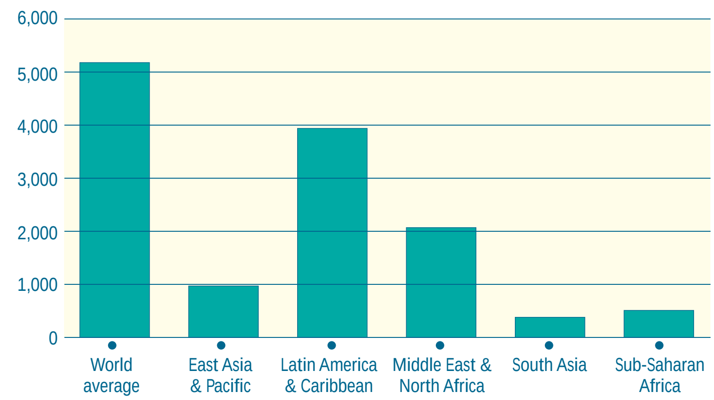
Food Needed To Achieve Food Security

Thousand tons



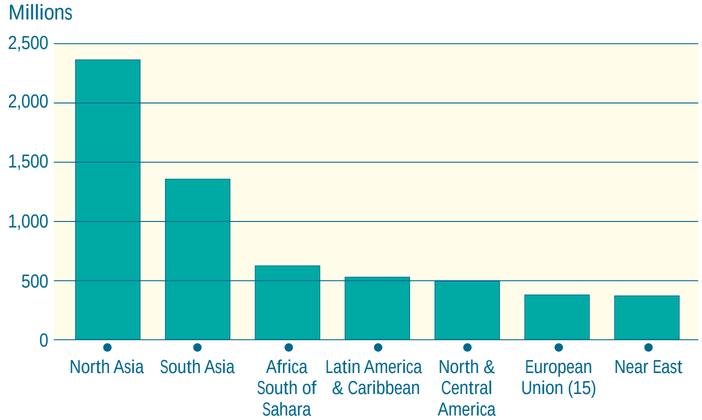
Per Capita Gross National Product

$/capita, 1997



World Population, 2001 Estimate (Total = 6.1 billion people)

Millions



II

Potential Benefits of Science and Technology

Developments in science and technology have contributed to better soil, nutrient, water, and pest management, and to more efficient methods of harvesting, storing, processing, and transporting farm products to market. Scientific breakthroughs have also occurred in our understanding of the complexity of sustainable agricultural systems, which has led to research into the development of sustainable crop management technologies and practices based on ecological principles.

Many factors influence technology adoption. Farmers choose from among alternative technologies and practices based on the biophysical characteristics of their environment, such as soil quality and access to water, as well as on social and economic characteristics such as land tenure, labor availability, income and wealth, profitability, and access to credit and information. Many of the scientific and technological advances made in recent years potentially could be adapted to developing-country needs to increase productivity and environmental sustainability. Ultimately, the choice of appropriate technology will depend on the context in which it is used. It may not be the "newest" technology, but it could still fulfill the sustainable production goals of the country in which it is used. Many of these technology adaptations that are appropriate for smallholders will need to be provided by the public sector or public/private partnerships.

Agricultural Production Technologies

Advances in soil and agronomic sciences have shown that application timing and method can be as important as input quantity for the effective use of fertilizers, pesticides, and irrigation water. Efficient input use results in fewer residues such as chemicals and salts accumulating in the environment. Knowledge of crop biological needs and resource conditions is often a critical input in crop management systems. There

Agricultural research has contributed to increased crop yields, a safer food supply, and improved environmental quality by:

- Developing new plant varieties with better resistance to cold and insects, and with greater tolerance of drought and flooding,
- Developing biological insect control methods to reduce the use of chemical pesticides,
- Eradicating major animal diseases, including hog cholera and Avian influenza,
- Developing a treatment for milk products that enables lactose-intolerant people to consume them,
- Designing methods to help track foodborne pathogens and modernizing inspection of food processing plants,
- Conducting organic farming experiments with novel cover crops, mulches, soil solarization, and biological control agents, and
- Developing soil management practices to curb the erosion rate of cropland.

are many types of crop management systems, ranging from chemical-intensive practices to organic production systems. The choice of appropriate practices to ensure a sustainable agricultural system depends on the characteristics of the environment in which the practices are used. Indigenous knowledge is important in designing an appropriate technology development plan, which needs to be in harmony with people, their societies and cultures.

Soil management

Soil erosion is not always visible and dramatic. In many areas, erosion by wind or water occurs slowly but steadily, and may not be recognized until damage is severe. In addition to the loss of productive soil, chemicals often adhere to soil particles and are transported by the erosion process to the environment. Tillage and land management systems have been developed to reduce soil disturbance, maintain optimal water-holding capacity, and increase soil nutrients and organic matter. Many of

Organic Production

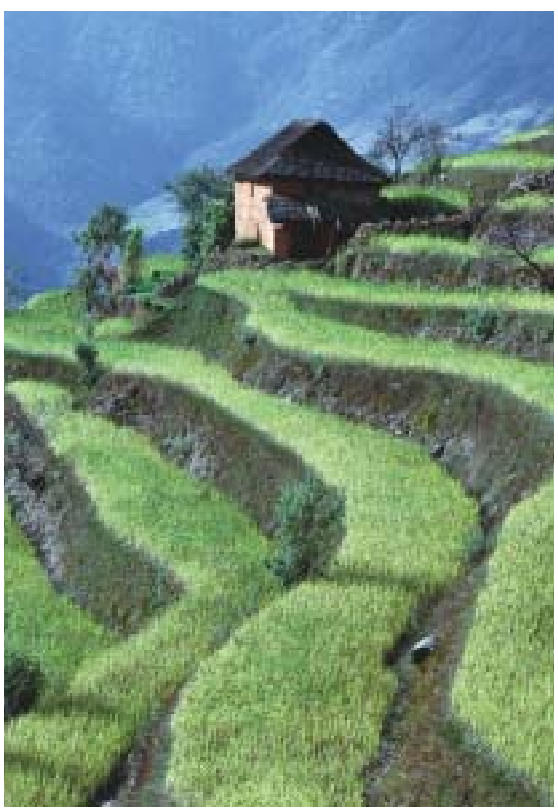
Organic production systems in the United States are managed to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity.

Organic Crop Production

Under organic farming systems, the fundamental components and natural processes of ecosystems, such as soil organism activities, nutrient cycling, and species distribution and competition, are incorporated as farm management tools. For example, habitat needs for food and shelter are provided for predators and parasites of crop pests, planting and harvesting dates are carefully planned and crops are rotated, and animal and green manures are cycled in organic crop production systems. The use of synthetic chemicals is virtually excluded in crop production.

Organic Animal Production

Organic livestock production systems attempt to accommodate an animal's natural nutritional and behavioral requirements. Organic livestock standards address the origin of each animal and incorporate requirements for living conditions, access to the outdoors, feed ration, and health care practices suitable for particular species. Antibiotic and hormone use is prohibited in livestock sold as organic.



Soil Management

Conservation tillage is a tillage system that leaves at least 30 percent of the soil surface covered by crop residue after harvest to protect the soil from erosion by water and wind. Types of conservation tillage include mulch tillage, ridge tillage, and no-tillage. In addition to reducing soil erosion and improving water quality, other benefits of conservation tillage include improving the quality of agricultural soil by increasing organic matter, sequestering carbon, and providing habitat and food for wildlife.

Contour farming and terracing refer to farming sloping land in such a way that maximum planting area is preserved following established grades or construction of earth embankments or channels.

Cover or green manure crops are close-growing grasses, legumes, or small grains grown primarily for seasonal protection or soil improvement. When these crops are plowed into the field, they add organic matter and improve infiltration, aeration, and tilth.

Grass and legumes in rotation are planted and maintained for a definite number of years as part of a conservation cropping system.

Filter strips are vegetative areas for removing sediment, organic matter, and other pollutants from runoff and wastewater. Filter strips are typically applied at the lower edge of fields, on fields, on pastures, or in manure-spreading areas adjacent to water bodies.

these technologies and practices can be adapted to meet the soil conservation needs of a developing country.

It is estimated that in 1996, U.S. conservation tillage reduced soil erosion caused by water by about 66 million tons, and by wind by about 31.5 million tons. The Global Assessment of Soil Degradation (GLASOD) estimated that 38 percent of the world's cropland has been degraded to some extent as a result of human activity since World War II (including 65 percent of cropland in Africa, 51 percent in Latin America, 38 percent in Asia, and 25 percent in North America, Europe, and Oceania). GLASOD identified erosion as the main cause of degradation (affecting 4 billion acres, mostly in Asia and Africa), followed by loss of soil nutrients (336 million acres, mostly in South America and Africa) and salinization (190 million acres, mostly in Asia).

Water management

There are many demands for high-quality water supply for municipal, industrial, agricultural, and, increasingly, environmental uses. In 2000, worldwide freshwater use is estimated to have been about 70 percent for agricultural, 20 percent for industrial, and 10 percent for domestic use. However, Sub-Saharan Africa uses only 2 percent of its freshwater resources for irrigation. The productivity of irrigated land is very high in both developed and developing countries.

Water is the most common medium through which contaminants are transported to the environment. Whether through rainfall or irrigation, agricultural chemicals and nutrients can flow beyond the field or percolate to the water table. Irrigation systems also can cause waterlogging, salinization, and groundwater depletion. Therefore, efficient water management in all sectors is important for achieving a sustainable agricultural system. For individual farmers, the choice of irrigation methods is often limited by the water storage and delivery capabilities of the region, the quality of the land, water institutions, and investment requirements.

Irrigation technology innovations have contributed greatly to agricultural productivity, particularly in arid areas and for specialty crops. Technological improvements made in water storage and conveyance have reduced energy use and water losses. In some areas, small-scale irrigation projects have been very successful. On-farm low-volume systems such as

The observations of an experienced farmer may be as effective as data from soil probes and meteorological stations in making an irrigation decision.

Irrigation Water Management

Gravity Flow Systems

Many irrigation systems rely on gravity to distribute water across the field. Land treatments—such as soil borders and furrows—are used to control lateral water movement and to channel water flow down the field. Gravity systems are best suited to medium- and fine-textured soils with higher moisture-holding capacities; field slope should be minimal and fairly uniform to permit controlled advance of water.

Pressurized Systems

Pressurized systems—including sprinkler and low-flow irrigation systems—use pressure to distribute water. With rare exceptions, the pressure to distribute water results from using pumps, which requires energy. With ***sprinkler systems*** water is sprayed over the field surface, usually from above-ground piping. Sprinklers may be operated on moderately sloping or rolling terrain unsuited to gravity systems, and are well suited to coarser soils with higher water infiltration. ***Low-flow irrigation systems***—including ***drip, trickle***, and ***micro-sprinklers***—use small-diameter tubes placed above or below the field's surface. Frequent, slow applications of water are applied to soil through small holes or emitters. Water is dispensed directly to the root zone, reducing runoff or deep percolation and minimizing evaporation. Pressurized systems, while more flexible in meeting crop water demands, require more energy and higher investment costs.

drip irrigation, which was developed in the Middle East, have provided yield benefits in addition to per-hectare water savings. Currently, equipment sensitivity and investment costs might make this technology inappropriate for some developing-country applications, but fundamental lessons of water delivery efficiency and on-farm water management can be adapted to local needs. For example, irrigation scheduling based on a crop's evapotranspiration rate and actual weather conditions could conserve water while increasing yields. Some low-cost irrigation technologies may be more beneficial in certain circumstances than those with higher investment or management requirements. The observations of an experienced farmer may be as effective as data from soil probes and meteorological stations in making an irrigation decision.

Pest management

The use of chemical pesticides in developed countries grew substantially after World War II. However, concerns about environmental contamination, ecosystem disruption, farm worker safety, and pest resistance led to substantial public research on alternative methods of pest management. If alternative pest control measures are not available, reductions in pesticide use may result in high production losses.

The goal of integrated pest management (IPM) research is to design systems for controlling pest damage that are appropriate for the site while reducing reliance on chemical pesticides. IPM programs often incorporate traditional practices, such as crop rotations, with sophisticated biological controls. Organic production systems do not use synthetic pesticides. Knowledge about pest biology and local

Integrated Pest Management

Techniques or practices collectively referred to as Integrated Pest Management (IPM) were designed to address some of the health and environmental concerns of pesticide use and to combat pest resistance to pesticides. IPM practices that meet production and environmental goals differ by crop, region, and pest problem. IPM attempts to capitalize on natural pest mortality factors: pest-predator relationships, genetic resistance, and the timing and selection of cultural practices such as tillage, pruning, plant density, and residue management. In practice, however, IPM is often based on:

- Scouting fields to determine pest populations or infestation levels
- More precise timing and application of pesticides based on scouting
- Better knowledge of the consequences of various levels of pest and predator populations
- Rotations
- More precise timing of planting.

environmental characteristics is important for the effective use of IPM. The use of biologically based pesticides such as Bacillus thuringiensis (Bt) and the introduction (or reintroduction) of natural predators can be part of a sustainable pest management system, but these technologies require more knowledge and management skills than simple pesticide application. In addition, success of IPM programs requires that all farmers in the area work together. Community action has been an effective tool for implementing IPM plans in some developing countries.

Humans have been altering the genetics of their food supply since plants and animals were first domesticated thousands of years ago.

Tunisian Success with IPM

Farmers in Tunisia reduced pest damages from the potato tuber moth by selecting integrated pest management (IPM) measures from a range of choices provided by the International Potato Center. Simple practices allowed the farmers to protect their health and the environment while cutting pesticide imports. Losses to the moth dropped by as much as 16 percent and the yearly benefits rose to US$3.25 million.

Source: Consultative Group on International Agricultural Research (CGIAR)

Nutrient management

Soil's productive capacity depends on the nutrient content that is available to the crop. Natural amendments to soil have been used for centuries: ash, manure, crop residue, and seaweed. However, the most productive balance of nutrients often was not achieved. Even if the optimum amount of one nutrient is met, other nutrients may be in excess supply and leach into the environment. Improvements in chemical fertilizer technologies have enhanced farmers' ability to increase production in developed and developing countries alike. Increased fertilizer use accounted for one-third of the growth in world cereal production in the 1970s and 1980s. Among developing regions, per-hectare fertilizer consumption increased most rapidly in land-scarce areas (such as in Asia) and most slowly in Africa. Excess fertilizer components that were transported to the environment caused concern and led to research on better nutrient management practices.

Knowledge about soil chemistry and structure was used to design systems to sustain the productivity of the soil while reducing nutrient losses to the environment. Technologies to test soil and plant tissue nutrient content have been

Nutrient Management

Several nutrient management practices have been designed to help farmers manage fertilizer use more efficiently while obtaining desired crop yields:

N-Testing– Soil and plant tissue nitrogen tests used to estimate the residual nitrogen available for plant use in determining fertilizer needs.

Split Nitrogen Applications– The application of half or less of the required amount of nitrogen for crop production at or before planting, with the remainder applied after emergence.

Nitrogen inhibitors can also be used to release nitrates later in the growing season to meet plant nutrient needs.

Micronutrients– Applied to the field either alone or mixed in bulk blended fertilizer, micronutrients are essential to plant nutrition but are needed in relatively small amounts.

Legumes in Rotation– Nitrogen-fixing crops (soybeans or alfalfa) are grown in rotation with other crops to improve soil fertility.

Manure– Animal wastes are applied to the field as a source of nutrient replacement.

Root Zone Application– There are several fertilizer application methods that ensure that the nutrients are readily accessible to the plant.

Banded, side-dressed, and ***injected*** applications are used in contrast to broadcast methods.

Chemigation is used in conjunction with irrigation.

improved to give farmers timely information that can be used in making decisions. These technologies can greatly enhance the efficiency of the use of manure, which is an important source of nutrients in many developing countries.

Biological knowledge is used to tailor nutrient applications to plant growth needs, in terms of both timing and quantity. Application technologies have been improved to deliver the nutrients close to the root zone, which increases the amount available for uptake by the plant while reducing losses of nitrogen to air and water resources.

Much of what has been learned about the chemical and biological aspects of nutrient management can be used to design systems that are in harmony with a country's sustainable agriculture goals.

Crop improvements

Increasing the yield potential and desirable traits in crops has long been a goal of agricultural science. Humans have been altering the genetics of their food supply since plants and animals were first domesticated thousands of years ago. About half of all recent gains in crop yields are attributable to genetic improvements. Innovations in plant breeding made in the public sector and international agricultural research centers after World War II produced the Green Revolution in many parts of the world.

Plant breeders have succeeded in developing crop varieties with high yields that will produce under particular pest pressures or environmental stresses. To obtain these benefits, however, investments in complementary crop management technologies such as irrigation or fertilizer use may be necessary. In addition, there is usually a gap—and it may be wide—between yields obtained in a laboratory or a controlled field trial and those actually experienced by farmers in their environment. Many innovations have to be adapted through further research, experimentation, and farmer involvement. Even with these efforts, there may be a need for major investments in complementary crop management technologies before yield or quality goals are reached. In addition, any new variety needs to be assessed with respect to its potential impact on the biological environment, such as its contribution to pest resistance, unwanted gene flow, or loss of biodiversity.

At the end of the 20th century, breakthroughs in molecular biology led to modern biotechnology and the development by the private sector of crops that are disease- and pest-resistant or herbicide-tolerant. Genetic engineering can increase productivity and achieve higher levels of stability and sustainability. Current farm-level biotechnology research is focused on developing crops that will tolerate a wider range of drought, acidity, salinity, heat, and flooding. These crops could contribute to productivity increases in resource-poor countries. For example, with the help of genetic engineering, scientists are developing a virus-resistant sweet

What Is Biotechnology?

Agricultural biotechnology is a collection of scientific techniques, including genetic engineering, that are used to create, improve, or modify plants, animals, and micro-organisms. Using conventional techniques, such as selective breeding, scientists have been working to improve plants and animals for human benefit for hundreds of years. Modern techniques now enable scientists to move genes in ways they could not before—and with greater ease and precision.

potato and pest-resistant variety of cassava. In South Africa, where 7 of every 10 cotton farmers have switched to biotechnology-derived varieties, farmers report that their production costs have decreased, and they use fewer pesticides. Also, the resulting reduction in tillage allows the soil to retain more water. Insect-resistant maize is being grown successfully by some small farmers as part of a pilot project supported by a biotechnology company.

Biotechnology tools also can be used for much more than just the production of bioengineered plants or animals. Tissue culture is the biotechnology tool used most frequently in developing countries. Many improvements in staple crops important to African people have been made recently with tissue culture. Molecular marker-aided selection methods can greatly speed the traditional plant breeding process, which can help crops respond more rapidly to pest pressures or environmental changes. Desired traits can be identified early in a plant's development rather than having to wait until maturity to observe the trait. This ability is particularly important for those plants

Precision Farming

Precision agriculture technologies result from innovations during the last decade in the computer, telecommunications, and satellite industries that have made more detailed spatial and temporal management of nutrients and other inputs within fields technically feasible. The application of these information technologies, known as precision farming or site-specific farming, enables producers to monitor and differentially manage small areas of a field that have similar soil or plant characteristics. Components of a comprehensive precision farming system typically include:

- Methods for intensively testing soils or plant tissues within a field
- Equipment for locating a position within a field via the global positioning system (GPS)
- A yield monitor
- A computer to store and manipulate spatial data using some form of geographic information system (GIS) software
- A variable-rate applicator for seeds, fertilizers, pesticides, or irrigation water.

More involved systems may also use remote sensing from satellite, aerial, or near-ground imaging platforms during the growing season to detect and treat areas of a field that may be experiencing nutrient stress.

and animals that take years to reach maturity. Monoclonal antibody technology uses immune system cells to make proteins called antibodies, which can be used as a diagnostic tool to locate substances that occur in minuscule amounts. For example, monoclonal antibodies can be used to detect harmful micro-organisms in food, to locate environmental pollutants, or to diagnose diseases in humans, animals, and plants more accurately than ever before. Another technology with similar uses for detecting and monitoring involves biosensors, which are composed of a biological component linked to a tiny transducer.

Biotechnology can be used to create bioengineered plants that can be used as manufacturing "facilities" for pharmaceutical compounds such as therapeutic proteins and vaccines. For example, researchers have developed a vaccine for hepatitis B that is produced by a banana for a fraction of the cost of a traditional vaccine. Crop plant production of these products may lower costs and increase supply compared to current pharmaceutical production. For developing countries, vaccine-producing plants might be easier to grow locally and make available to rural populations than current vaccines.

Precision farming

Precision agriculture is typically characterized as a suite of information technologies used to monitor and manage sub-field spatial variability. Farmers use satellite technology, computers, and robotics to manage the use of pesticides, fertilizers, and water more efficiently by tailoring input amounts to the specific characteristics of the site.

The benefits of precision agriculture technologies are greatest when field or farm conditions vary widely and the uniform applications of inputs will result in production inefficiency. Each location is tested and a site-specific management plan is designed for individual conditions. Soil testing and field mapping can be used to identify places in a field where additional nutrient use will increase yield, or where input use can be reduced while maintaining yield. Variable-rate application of seeds, fertilizers, pesticides, and irrigation water has the potential to enhance producers' profits by reducing input costs. It may also reduce the risk to the environment from agricultural production by tailoring input use and application more closely to ideal plant growth and management needs. In addition, by improving the efficiency of input use, precision farming has the potential to reduce the transport of agricultural chemicals through surface runoff, subsurface drainage, and leaching.

Because the investment cost is high relative to the value of information received, current precision farming technologies are not likely to be appropriate for use by farmers with small holdings in developing countries. The systems could, however, be of great value for technology development planners, especially in assessing the productive capacity of natural resources and the appropriate suite of technologies and practices to sustainably increase production. For example, decisionmakers could use the information derived from remote sensing or soil mapping to identify areas vulnerable to erosion or deficient in essential soil nutrients. They then could offer incentives

or provide technical assistance to those areas to encourage the adoption of technologies and practices that would reduce erosion or increase soil productivity.

Animals/livestock

Selective breeding has been used worldwide to increase production of those animals that are most productive for the environment in which they live. For several decades, a more reliable technology has been used where the sperm and eggs are taken from bulls and cows with genetically preferred traits. These cells are united in the laboratory and cultured before being implanted in surrogate cows. The results of this breeding method are more reliable in getting enhanced traits, and the quantity of desired offspring can be increased.

Animal health research has been an important factor in increasing productivity and product quality. Particularly in an era of global mobility, the rapid and accurate diagnosis of disease can slow the spread of infection. Quarantines and embargoes are most effective before a problem becomes widespread. Biotechnology-based diagnostic tests are more sensitive and easier to transport than older diagnostic methods. Diagnosing diseases such as brucellosis, pseudorabies, avian leucosis, or foot-and-mouth disease sooner and with greater accuracy means that appropriate therapy can be started sooner, thus decreasing the spread of the disease. Low-cost diagnostic technologies would be a valuable tool in the more isolated rural areas in developing countries where livestock health is critical for food security. Research is also being done to identify traits associated with disease resistance.

Recent research in developed countries has shown the benefits of integrating animal and crop production systems. By growing feed crops for their own animals, producers control the quality of the feed and may save on the purchase of inputs. In addition, the livestock waste can be used to increase soil quality. These integrated systems have been used throughout the developing world, but application of new scientific findings can increase productiv-

Low-cost diagnostic technologies would be a valuable tool in the more isolated rural areas in developing countries where livestock health is critical for food security.

Agroforestry Innovations Increase Dairy Production

Researchers from the International Center for Research in Agroforestry and national partners in Kenya have identified a leguminous fodder tree that can substitute for expensive commercial dairy meal. Using the calliandra tree can increase a farmer's income by more than US$150 per cow per year. With an estimated 400,000 small-holder dairy farmers in Kenya, the potential benefit from cultivating this tree exceeds US$100 million a year. Similar benefits can be reaped in highland countries such as Ethiopia, Tanzania, Uganda, and Zimbabwe.

Source: Consultative Group on International Agricultural Research (CGIAR)

ity and contribute to higher environmental quality. New technologies for nutrient testing and manure spreading reduce runoff and leaching of animal wastes and increase fertilizer benefits to the crop.

Forestry and biomass

Although forests are harvested to produce building supplies and paper products, there has been an increasing appreciation of standing forests as a valuable ecosystem that can provide biodiversity, wildlife habitat, recreational opportunities, and a source of carbon sequestration. Low-impact logging practices are being developed to replace clear-cutting practices and to preserve the integrity of the forest ecosystem while harvesting wood products. Conversion of forests for agriculture accounted for two-thirds of the world's deforestation during the last 20 years. The most successful reforestation and agroforestry projects have resulted from long-term planning by rural communities that were committed to improving the local natural resource base.

In many developing countries, trees and other woody vegetation are the primary source of fuel in rural communities. The need to gather wood in resource-poor areas often causes women and children to travel long distances carrying heavy loads. The production of accessible and sustainable sources of fuel could free household resources for other uses.

There is increasing interest in developing sources of biomass to substitute for fossil fuels. Bio-feedstocks can be relatively clean-burning and have less waste than petroleum-based fuels. In addition, extraction/harvest, when properly managed, has a low environmental impact. The technologies developed to improve the economic feasibility of biomass-derived energy may be useful for developing countries.

Aquaculture

One of the fastest growing segments of the world's food production is aquaculture. It represents an alternative to the wild harvest of some fish species that are threatened by pollution and overfishing, and provides an excellent source of protein. Aquaculture is the production of aquatic animals and plants under controlled conditions for all or part of their life cycle. Sometimes the level of control is minimal, while in other cases the environment is designed to mimic a closed ecosystem. For example, in shallow coastal

Aquaculture Provides a Source of Protein

Research done by the World Fish Center in Malaysia has produced an improved strain of tilapia, a hardy freshwater fish from Africa. Compared with other farmed strains, the resulting tilapia can grow 60 percent faster with better survival rates, and can yield three fish crops per year, rather than two. The fish provides a source of affordable protein in areas with limited resources. Tilapia farming in Asia has contributed to a rise in overall fish production for the first time in 5 years. The fish farmers have received higher yields and profits, with most overall benefits going to relatively poor consumers.

Source: Consultative Group on International Agricultural Research (CGIAR)

Increased production on the farm will not yield sufficient benefits if the products are not delivered in an acceptable form and a timely manner to an end-user.

waters, a frame can be placed to catch natural oyster spawn and the shellfish mature on the frame where they are easily harvested. In some areas, coastal oilrigs have inadvertently become shellfish nurseries.

The other extreme in aquaculture technology is the use of "farms" where fish are grown in tanks of constantly tested, filtered water. The feed is developed to meet the nutritional needs of the fish, and the animals are monitored for diseases that affect fish productivity and for organisms that might pose health hazards to consumers. A variation on this technology system for the intensive production of fish is called aquaponics, which combines the concentrated production of a vegetable or fruit crop as part of the recirculating system. Nitrogen waste from fish metabolites provides nutrients to the crop. By removing these wastes, the vegetation filters and cleans the water, which promotes faster fish growth.

Marketing, Processing, and Transportation Technologies

In developed countries, the choices of foods that are readily available to consumers have expanded greatly in the past two decades. Innovations in storage, transportation, processing, and marketing have made the increase in affordable products possible. In these countries, much of the research on postharvest technologies has been done in the private sector. Many of these innovations can be adapted for developing-country needs through collaboration with a range of institutions from developed and developing countries.

Increased production on the farm will not yield sufficient benefits if the products are not delivered in an acceptable form and a timely way to an end-user. Major innovations in transportation have reduced the costs of long-distance trade and have increased opportunities for expanding markets. These reductions in

transportation cost will lower the price of the product and make it more available both geographically and economically. The objective of product transportation is to get products to market while maintaining quality and reducing handling and time in transit. The use of large, standardized containers that can be transported by truck, train, and ship without repacking has significantly lowered transportation costs in developed countries. For developing countries, containerization allows ports to greatly increase shipping capacity.

The shelf life of fresh fruits and vegetables and their durability for transport have been increased, although in the past these traits often came at the expense of taste. Edible food films have been developed to reduce spoilage and dehydration of fresh fruits and vegetables. Recent genetic research is focused on targeting the desired traits that consumers demand. In developing countries, affordable, small-scale technologies for preserving vitamin-rich fruits and vegetables can help combat micronutrient deficiencies by ensuring an adequate diet throughout the year. Technologies are also needed to accumulate, treat, and deliver perishable commodities such as milk that are produced on many geographically dispersed small holdings.

Foodborne illnesses are caused primarily by micro-organisms such as bacteria, viruses, molds, and parasites. Food safety hazards can come from unclean water, lack of refrigeration, and unsanitary conditions for food transport, storage, marketing, and preparation. Food safety can be increased by the use of new technologies. The use of biosensors in processing plants reduces contaminants and enhances quality. Also, product quality characteristics can be identified with the use of sensory panels. Irradiation will reduce food-borne pathogens and may be an effective method to use for fresh produce, especially when pre-harvest contamination from the use of manure fertilizers may occur.

Enhancing the amount of essential amino acids, vitamins, and minerals in foods is particularly valuable for countries where food sources are limited.

Computer and communication technologies have improved quality control for production and the ability to market agricultural products efficiently. Food safety monitoring technologies and sanitary practices have greatly reduced microbial contamination. Rapid testing for mycotoxins, pesticides, and other environmental contaminants is extremely important in meeting international quality standards. Production wastes are being reduced or recycled more frequently than in the past.

Food-processing technologies have been used to transform raw agricultural commodities to meet consumer demands. Convenience is one characteristic that consumers have requested, along with enhanced flavor and nutritional content. Raw materials are being produced from traditional plant breeding and biotechnology methods to have higher contents of desired processing traits such as oils or starch, and lower amounts of other traits such as allergens.

In developed countries, several staple foods, such as bread and milk, are routinely fortified with vitamins. These additions have drastically reduced the incidence of rickets, scurvy, goiter, and other afflictions caused by nutritional deficiencies. Research is active in the area of functional foods that contain biologically active components that impart health benefits, which will eliminate the need to add the components later. This breakthrough would be particularly valuable for rural populations who consume food locally rather than purchase processed food. For example, a new tomato variety has been developed with three times the amount of the cancer-fighting antioxidant lycopene. Scientists in Europe have found a way to create nutritionally enhanced rice that could provide a source of vitamin A. This Golden Rice could reduce the number of children afflicted with vitamin A deficiency-caused death or blindness. Enhancing the amount of essential amino acids, vitamins, and minerals in foods is particularly valuable for countries where food sources are limited.

Innovations for the Future

Many have described the beginning of the 21st century as the Information Age. Precision farming and biotechnology resulted from the increased ability to analyze information. Innovations in computing capabilities and low-cost access to computers have dramatically enhanced the ability to store and analyze data. In addition, today's communication networks allow the rapid exchange of information. Firms can assess consumer demands worldwide, farmers can produce value-added crops for specific markets, and scientists can collaborate with researchers around the world to gather and analyze data.

Developments in multiple scientific disciplines have led to exciting discoveries, and to the origin of several new fields: bioremediation, nanotechnology, genomics, and bioinformatics. There is no way to predict exactly how these will affect developing-country agriculture, but they will all add to the foundation of knowledge on which scientific and technological discoveries are made.

Bioremediation

Research in both natural and physical sciences has shown that plants and microbes can be used to remove contaminants from the environment. Bioremediation techniques are being developed to clean up oil spills, hazardous wastes, and other pollutants. Enhancing the biocatalytic characteristics of some plants would be valuable in particular developing regions where harsh environments, depleted resources, or unusual habitats preclude production with current technologies.

Nanotechnology

The development of microscopic tools for imaging and manipulating single molecules has led to the exciting new field of nanotechnology. Ultra-small structures and machines are being made of as few as one molecule. Bio-nanotechnology may give molecular biologists even greater opportunities to investigate the physiological functions of plants and animals, which can increase the speed and power of disease diagnosis.

Genomics

Genomics is the study of the genome and the biological roles genes play, individually and collectively, in determining structure, directing growth and development, and controlling biological functions. Public and private projects have generated genome maps and complete deoxyribonucleic acid (DNA) sequences of several organisms. Two biotechnology companies donated research results to the international effort to produce a complete genetic map of rice. Genetic sequence information can be used to develop diagnostic tests, find genetic markers, identify genetic susceptibilities, and develop therapeutics. The role genes play in biological functions involves protein production. Genes exert their effects through proteins, but less is known about the link between proteins and biological function. Proteomics is the study of the structure, function, location, and interaction of proteins within and between cells.

Bioinformatics

This technology uses statistical software, graphics simulation, and database management to consistently organize, access, process, and integrate data from different sources. Specific activities may include screening chemical compounds, identifying potential pharmaceutical drugs, and determining plant and animal genes to improve sustainable agricultural production. Bioinformatics has already been used to form international databases that are available to scientists around the world via the Internet. In this way, the quality of the data on plants, animals, and microbes can be assessed, and the information made accessible to researchers in both developed and developing countries.

III

Support for Technology Development and Transfer

In any particular country, a variety of economic, social, environmental, and institutional factors can create high barriers to technology development and transfer. These factors will be discussed under broad headings:

- Systems for providing scientific research, public health, and education,
- Economic infrastructure, such as transportation and communications networks,
- Financial, legal, and political institutions, including intellectual property rights,
- Natural resources and environmental regulations, and
- International treaties and trade policies.

Support for technology development and transfer includes contributions to reducing barriers and increasing incentives.

Research, Health, and Education Capacity

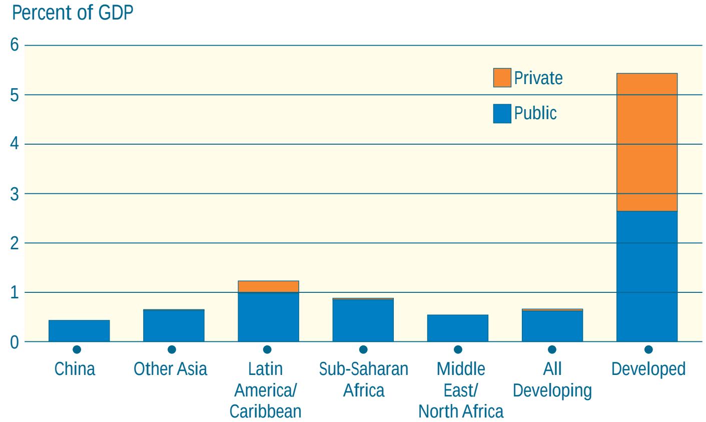
Research systems—both public and private—play a critical role in developing new productivity-enhancing agricultural technology, as well as in facilitating technology transfer and adaptation to developing countries. Scientists with knowledge of local crops and environments are crucial for ensuring the selection and development of appropriate technologies. Issues of finance and governance are relevant to the performance of agricultural research, just as they are in other areas of public investment or public policy. Developing political support for public sector agricultural research, finding the means of financing such research, and setting priorities that are reflected in the allocation of research budgets are important policies that support technology development and transfer.

The Importance of Infrastructure

There are many characteristics of a developing country that will determine the success of technology transfer activities, business endeavors, or other ventures. The term "infrastructure" is often used to represent these characteristics. Webster's Dictionary defines infrastructure as "the underlying foundation or basic framework, and ... the permanent installations required for operation." The institutional, economic, and physical conditions of a country (its infrastructure) represent the environment in which activities can successfully take place. In the context of the role of science and technology for increasing the capacity of developing countries to benefit from global trade, there are three types of critical infrastructure:

- Research, health, and education systems
- Transportation and communication networks
- Financial, legal, and political institutions.

Agricultural R&D Expenditures as Percent of GDP, 1995



Most low-income countries do not have large financial resources to invest in the training of scientists, maintenance of research facilities, or many other components of a strong agricultural R&D program. Asian countries have been able to invest more than most countries in Africa, as is reflected by the relative levels of per capita food production in the two regions. The average level of agricultural R&D expenditure in Asia, however, is still below the world average. Since resources may not be available for domestic investment in research, there is a need to transfer technologies to increase agricultural productivity and income. But technology transfer entails more than just shipping machines, seeds, or blueprints. Experts with knowledge of their country's characteristics are needed to adapt technologies and to develop effective incentives to ensure adoption and efficient use.

Internet-Based University

A recent innovation in higher education is the development of Internet-based university programs. The earliest experiments were in business-related fields. One U.S. on-line university has about 60,000 students attending classes through the Internet, and 4,000 of these are from overseas. For some fields, particularly in the bench sciences, personal interaction and extensive classroom and laboratory time are still important for part of the training. Current on-line programs are expensive, but may be cost-effective for developing-country students, compared with international travel and time away from jobs and family.

The Consultative Group on International Agricultural Research (CGIAR)

CGIAR is an association of public and private members supporting a system of 16 Future Harvest Centers that work in more than 100 countries to mobilize cutting-edge science to reduce hunger and poverty, improve human nutrition and health, and protect the environment. The CGIAR partnership includes 24 developing and 22 industrialized countries, 4 private foundations, and 12 regional and international organizations that provide financing, technical support, and strategic direction. Individual members make voluntary contributions to the Centers and programs of their choice, allowing funds to be targeted to areas of research and regions that align with development priorities. All benefits of CGIAR research are kept within the public domain, freely available to everyone.

The 16 Future Harvest Centers of CGIAR are:

CIAT – International Center for Tropical Agriculture, Colombia

CIFOR – Center for International Forestry Research, Indonesia

CIMMYT – International Maize and Wheat Improvement Center, Mexico

CIP – International Potato Center, Peru

ICARDA – International Center for Agricultural Research in Dry Areas, Syrian Arab Rep.

ICLARM – World Fish Center, Malaysia

ICRAF – World Agroforestry Center, Kenya

ICRISAT – International Crops Research Institute for the Semi-Arid Tropics, India

IFPRI – International Food Policy Research Institute, USA

IITA – International Institute of Tropical Agriculture, Nigeria

ILRI – International Livestock Research Institute, Kenya

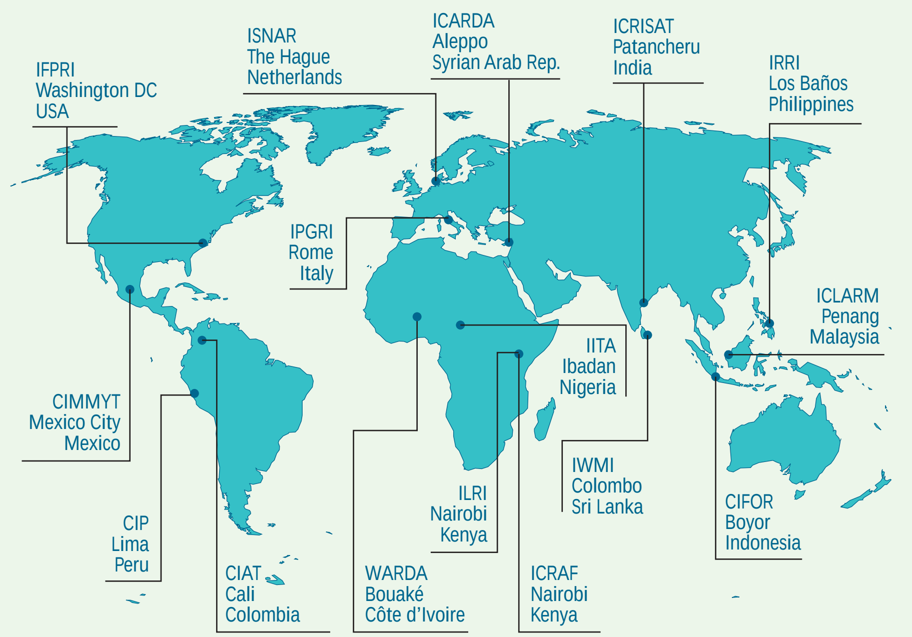
IPGRI – International Plant Genetic Resources Institute, Italy

IRRI – International Rice Research Institute, Philippines

ISNAR – International Service for National Agricultural Research, The Netherlands

IWMI – International Water Management Institute, Sri Lanka

WARDA – West Africa Rice Development Association, Côte d'Ivoire



Labor quality may vary with differences in experience and education, making investment in basic education another potential complement to investment in agricultural research.

Research infrastructure in the poorest regions can be improved through direct investment in facilities and education in the developing country, and through the support of such organizations as the World Bank, the Rockefeller Foundation, and the Consultative Group on International Agricultural Research (CGIAR). International collaboration in public agricultural research has been very successful in transferring basic and applied knowledge throughout the world.

Complementary public investments may also influence the success of agricultural research and technology transfer. A strong public health system is important to the success of new agricultural technology and to the development of agriculture generally. If the agricultural labor force is in poor health, it will be much more difficult to raise agricultural productivity with or without new technology. Malaria, tuberculosis, and other chronic diseases as well as the prevalence of micronutrient deficiencies compromise food and nutrition security.

Education is important at all levels to support the development and transfer of science and technology. In addition to the scientists directly involved in research, there is a need for trained individuals to develop and implement regulations that affect technology use. Qualified people are also needed to represent their country's interests in international negotiations. Decision-makers need the expertise to understand the positive and negative implications of their actions within the complex human and ecological environment of their country.

Labor quality may vary with differences in experience and education, making investment in basic education another potential complement to investment in agricultural research. Particularly for knowledge-intensive technologies such as precision agriculture, farmer education may be crucial to adoption. It is important that educational opportunities be nondiscriminatory, for example on gender or ethnic grounds. Women often make the agricultural production decisions, and their knowledgeable input into technology choices is essential.

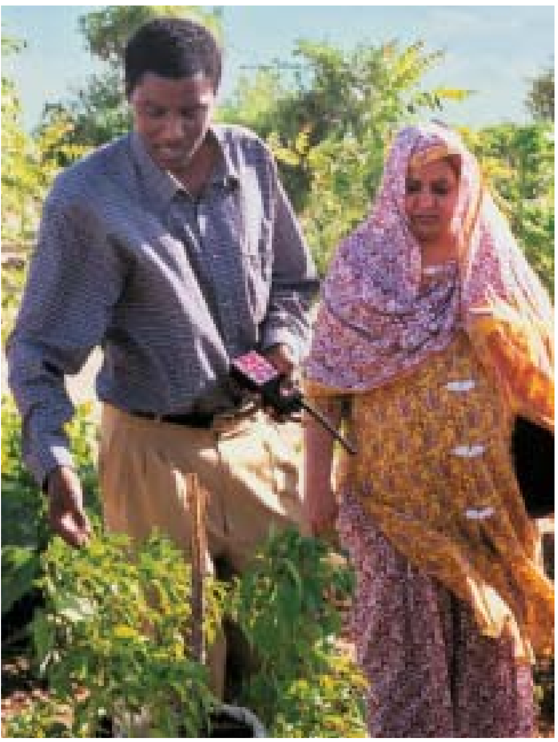
Economic Infrastructure

Economic infrastructure includes services from public utilities such as power, telecommunications, water supply, and sanitation and sewerage; and from public works and transport systems such as dams and canals for irrigation and drainage, roads, railways, airports, ports, and waterways. Infrastructure can be highly complementary to science and technology in increasing agricultural productivity, and lack of infrastructure can seriously constrain agricultural development.

For example, those countries that had poor transportation, irrigation, and financial systems did not benefit from the Green Revolution technology as much as those countries that did. Green Revolution technology was most closely associated with new crop varieties that were combined with increased use of fertilizer in areas with irrigation or more rainfall. The countries in which high-yielding varieties were most successful also had functioning roads, irrigation systems, options for credit, and markets and distribution channels.

A functioning agricultural market is dependent on a strong communication infrastructure. Rural areas rely on public information to be integrated into the national economy. Basic communication that needs to be made available includes information about health and sanitation hazards, weather, public transportation schedules, labor and market opportunities, and rights to public resources. Information from scientists and agricultural experts about production practices needs to be disseminated as widely as possible. Moreover, as farmers vary production to include horticulture, vegetables and fruits, and other products that must be delivered quickly, there is a premium on real-time information about markets.

Information and communications technology has been transformed throughout the world, by computer and Internet use and by wireless telephone technology. These innovations can help farmers in all countries by providing up-to-date market and labor information. These innovations can also serve to provide educational opportunities and timely transmission of critical information. For those farmers in developing countries with Internet access, agricultural extension information and research results can be disseminated widely. Farmers could also alert researchers to emerging pest pressures and environmental conditions. To make this technology more effective in smallholder agriculture, however, literacy and physical infrastructure, such as electrical power, must be as widely accessible as possible.



Cell Phone Use in Bangladesh

The Village Phone concept in Bangladesh was developed by a not-for-profit company called Grameen Telecom (GTC). In partnership with GrameenPhone Ltd and the Grameen Bank, GTC has established the cell phone equivalent of the public pay phone in remote areas without land-line phone service. A Grameen Bank member obtains ownership of the phone under a lease-financing program and provides the services to the people in the adjoining area. The operator receives an income from the use of the cell phone. GTC supplies the necessary hardware and provides training for operating the phone. With this service, each villager has access to labor and agricultural marketing information. Women all over Bangladesh are buying cell phones using loans from a network of microfinance loan institutions that the U.S. Agency for International Development (AID) helped establish. Grameen estimates that one Village Phone covers approximately 2,500 people in a village, and the total coverage is currently 12.5 million rural people in Bangladesh.

Domestic expertise that is fostered by strong research and education capacity will be needed to make decisions that are based on sound science and that meet the needs of the country.

Financial, Legal, and Political Institutions **(Institutional Infrastructure)**

The introduction of new technologies requires new policies to ensure health, safety, or environmental quality. Stable institutions are important for long-term planning and investment in technology development. Open and transparent investment regulations that are compatible with global trading rules will encourage both domestic and foreign investment. Perceived fairness will also encourage participation at all levels, which will encourage foreign investment as well as farm-level cooperation with technology development plans. Well-functioning markets that operate internationally and locally depend on the strength of a country's financial, legal, and political institutions. Private investment in technology development and transfer from domestic and foreign sources will not be forthcoming without a strong demand by farmers and a well-functioning infrastructure.

Financial institutions provide capital for research, physical infrastructure, and farm credit. Devising agricultural credit systems that fit the needs of smallholders has been difficult in many countries, especially those with large income gaps, complex land ownership, weak banking systems, and under-employment. This is an important barrier because many new agricultural technologies require the use of purchased equipment or inputs, making credit essential to their widespread use.

Legal institutions often reflect a country's social history. Rights and private asset ownership will determine who has access to institutional assets such as education, finances, or the right to participate in the political process. For agricultural producers in developing countries, control of land is often a critical determinant of technology adoption. Investment in agricultural technology is often related to a farmer's security of land tenure. In addition, natural resource conservation efforts with long-term benefits may be hampered without land tenure security. As mentioned above, contracts that could facilitate better access to inputs or improved markets need to be legally enforceable.

Political institutions need to be stable to support opportunities for agricultural development. Yet the political environment of a country is more than just the formal deliberations of a national leader or a legislative body. It includes the planning, administrative, regulatory, and enforcement functions that are often dismissed as "merely bureaucratic." These functions, if performed efficiently, are critical to the research, development, dissemination, and adoption of science and technology.

Development planning must have the support of government leaders and the general population so that agricultural production and environmental quality goals reflect the true needs of the country. The benefits of any development plan will increase when science and technology policies are integrated in the plan, and when there is a framework to implement the decisions. Technical support for planning from other countries may be needed, but the goals and objectives must be national.

In support of planning and implementation, there is a need for a regulatory process that is designed to protect the health and well-being of the people and the environment. The assessments of new technologies need to be done quickly and thoroughly. Domestic expertise that is fostered by strong research and education capacity will be needed to make decisions that are based on sound science and that meet the needs of the country. Regulatory frameworks and testing protocols from other countries can be used as models. Domestic scientists and technical experts, however, are needed to monitor and adapt implementation to regional circumstances.

In many countries, a tension exists between agricultural and environmental interests, even within the government. With increased understanding of the complex interactions between agricultural production and environmental assets, opportunities arise to develop a science and technology plan that supports a country's agricultural development and environmental quality goals. In some countries, there is no regulatory system within which science-based decisions can be made. Without such a system, potentially beneficial innovations and technologies are not being considered for investment or adoption.

Several specific components of the institutional infrastructure are particularly important for understanding barriers to science and technology transfer: A nation's system of intellectual property rights, access to germplasm for research, and the body of domestic agricultural policies will all influence relative prices and incentives for public and private research.

Intellectual property rights (IPR)

This is one set of legal rights of particular importance to research and technology transfer. As the United Kingdom's Commission on Intellectual Property Rights stated, "(t)he critical issue in respect of IPR is perhaps not whether it promotes trade or foreign investment, but how it helps or hinders developing countries to gain access to technologies that are required for their development." Currently, the lack of comprehensively specified and enforceable intellectual property rights constitutes a major barrier to the sharing of knowledge and technology among countries, and a disincentive to local and foreign research investment in new technologies. In general, nations that generate technology prefer strong intellectual property protection, while those that depend on imported technologies prefer few restrictions on the use and imitation of that technology.

Over the past 20 to 30 years, intellectual property systems have become increasingly important factors affecting research in industrialized countries. Intellectual property mechanisms, such as patenting, confer exclusive rights to inventions for a limited time, to offer an incentive for research and to protect private sector investment in new technologies and products by restricting the use, sale, and manufacture of these innovations. Research investment can be costly, and the probability of success low. Many firms would not risk funding research if

Local Company Sells Seeds to Small-Scale Farmers

Pannar is the oldest domestic maize seed company in South Africa, and it has just over half of the market. The privately held company has prospered because the strong South African laws protecting intellectual property rights have encouraged companies to invest in the agricultural sector. Pannar provides the latest hybrid seeds to commercial growers at competitive prices. In addition, the company has maintained cheaper maize seed products that are a generation behind the latest hybrids but are nonetheless productive under South African growing conditions. Pannar provides these seeds at affordable prices to small-scale farmers, which has increased agricultural productivity. South Africa provided the investment environment that offered incentives for private businesses to support national goals.

Plant Variety Protection

Rules and regulations governing plant variety protection, or plant breeders' rights, and patents for biological innovations differ widely among countries.

Plant Breeders' Rights in the U.S.

In the U.S., the Plant Variety Protection Act (PVPA) was adopted in 1970. The main features of plant breeders' rights legislation are the:

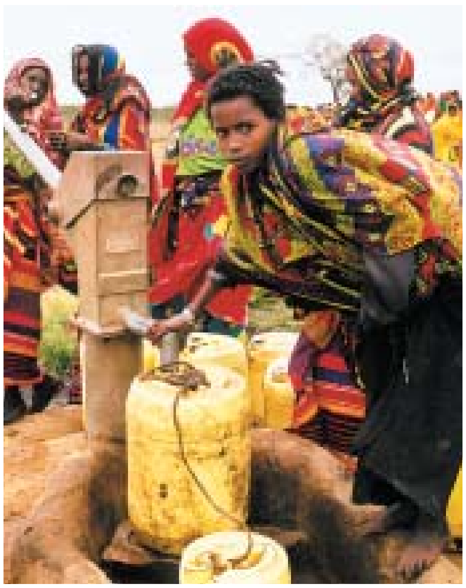
- definition of a distinct variety (as opposed to an "essential derivative")
- rights of farmers to save seed for their own use (or to re-sell it)
- research exemptions for use in other breeding programs
- time period covered by the grant of a certificate.

These provisions are consistent with the International Union for the Protection of New Varieties of Plants (UPOV), which took effect in 1968. In 1985, utility patent protection in the U.S. was extended to plants.

Plant Breeders' Rights Outside the U.S.

Most Western European countries passed plant breeders' rights legislation in the 1960s and 1970s. Australia and Canada adopted plant breeders' rights around 1990. Other industrialized countries have been more reluctant than the U.S. to grant patent protection to living organisms, although the European Patent Office in 1999 moved to grant patents on genetically engineered crops. Most key elements of intellectual property protection systems in Europe and Japan are similar to those in the U.S., although important distinctions remain with respect to the treatment of plants and animals and the scope of patentable matter.

Some developing countries such as Argentina instituted plant breeders' rights as early as the 1930s, but most do not have intellectual property protection systems that are comparable to those in developed countries.



Developing countries may not have the resources in research and legal infrastructure to obtain needed inputs for scientific developments.

African Agricultural Technology Foundation

In concert with the Rockefeller Foundation, four agricultural technology giants, Dow Chemical, DuPont, Monsanto, and Syngenta, have agreed to share their patented technologies for free with the African Agricultural Technology Foundation (AATF). The U.S. Agency for International Development is contributing to the effort. The AATF is an experiment—a new concept designed to aid in the transfer of promising new technologies developed by the private sector to advance African agriculture. The focus will be on facilitating research on improvements in staple crops of vital importance to Africans, including cowpeas, chickpeas, cassava, sweet potatoes, bananas, and maize.

The AATF is a nonprofit organization designed to facilitate the transfer, adaptation, and adoption of agricultural technologies by small farmers in Sub-Saharan Africa. The organization is controlled by a majority African board to ensure that sustainable development and agricultural ecology goals of Africans are met. The organization's key role will be in licensing technology from the private sector and contracting with African and other organizations to ensure that licensed technology is appropriately adapted and reaches farmers.

Finding technological solutions to many of Africa's problems—such as drought, insects, and plant diseases—often involves a thicket of patent rights, licensing and cross-licensing arrangements, and private interests that run counter to solving these problems. The AATF will cut through this thicket by making royalty-free license agreements with the four firms and get the new technologies and improved seed varieties into the hands of small farmers of local staple crops.

Public Sector Intellectual Property Resource for Agriculture

An effort called the Public Sector Intellectual Property Resource for Agriculture (PSIPRA), developed by the Rockefeller and McKnight Foundations, is designed to support plant biotechnology research in developing countries. The PSIPRA will encourage public universities that license their patented agricultural technologies to private firms to retain some rights to the technologies for humanitarian purposes. In some cases, these technologies would be applied to small specialty crops. The first objective of PSIPRA is to establish a clearinghouse to facilitate access to biotechnology innovations by providing information on existing patents and emerging technologies and to provide educational and information services to help institutions implement effective licensing strategies.

they were unable to obtain a return on the investment. Therefore, new technologies become available earlier than they would without intellectual property protection.

While intellectual property protection has been a feature of chemical and mechanical innovation in industrialized agriculture for some time, changes in intellectual property protection that have had the greatest impact on agricultural R&D have involved biological innovation. The two major forms of protection are plant varietal protection, or plant breeders' rights, and the application of utility patents both to plants and to biological research tools.

Although intellectual property protection may speed some inventions to the market, exclusive rights to fundamental innovations may impede further technological progress. Often, technology development is cumulative, and scientific advances depend on past innovations. Restrictions on the use of innovations for research could limit future research or needed adaptations of past inventions. This barrier to research is an issue in developed as well as developing countries. Partnerships between public institutions and private companies often include provisions to grant access to public research results.

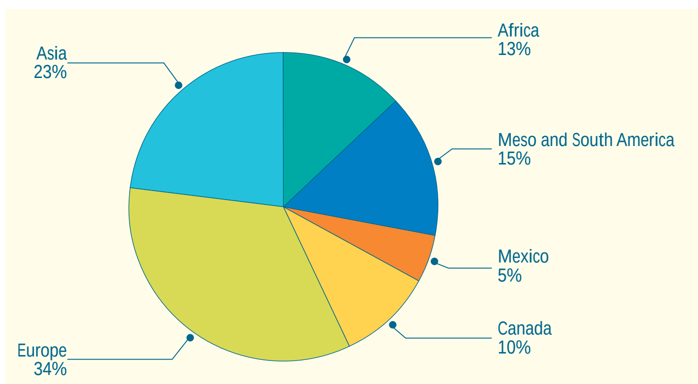
Many are concerned that private commercial research will not be done on crops that are important for local staple crops, and that public research entities will not have access to the basic discoveries necessary to develop technologies to fill smallholder needs in developing countries. For example, in the case of enhanced vitamin A rice, the innovation is based on technologies protected by around 70 patents originally held by about 30 different institutions. To use the research innovation, scientists (or their organizations) would have to negotiate with each patent holder for use of the rights. Developing countries may not have the resources in research and legal infrastructure to obtain needed inputs for scientific developments. In some circumstances, opportunities may exist to create public-private alliances and joint ventures to develop appropriate technologies in developing countries.

Germplasm access

Crop improvement through traditional plant breeding methods and modern biotechnology depends critically on crop genetic resources. Pests, pathogens, and climates change continually, so breeders need new genetic resources from which to choose desired traits. For example, germplasm is used in a research program to search for resistance to or tolerances of biotic stresses. Even though many sources of germplasm are located in developing countries, the usefulness of these resources to these countries depends on research funding and infrastructure to utilize the materials.

International use of the U.S. National Plant Germplasm System (U.S. NPGS) collection of seeds, plants, and other germplasm materials plays an important role in providing public germplasm free of charge to scientists and institutions in other countries. During the past decade, the U.S. NPGS distributed 162,673 germplasm samples of 10 major crops (barley, beans, cotton, maize, potato, rice, sorghum, soybean, squash, and wheat) to scientists in 242 countries.

International Distribution of U.S. National Plant Germplasm System Germplasm for 10 Major Crops, by Region, 1990-99



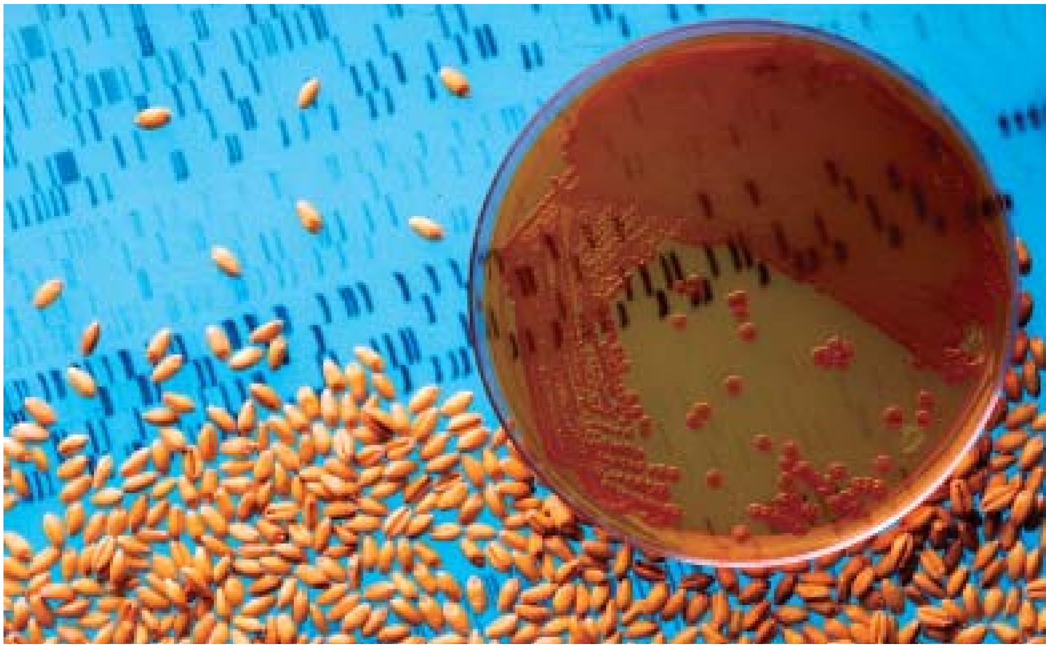
Given economic and environmental constraints on cropland expansion, the bulk of increased crop production in the future must come from increased yields on existing cropland.

The International Plant Genetic Resources Institute also shares genetic resources with the scientific community, and has helped to establish over 1,300 national and regional genebank collections. Enhanced availability of genetic resources and increased indigenous research capacity will make it easier for crops to be developed to meet the unique needs of each developing country.

Historically, plant genetic material was freely collected and shared. Developing countries—with a wealth of biological diversity in situ (in the wild and on fields)—often provided raw genetic material to public genebanks worldwide. However, international policy has moved toward a system in which countries retain rights over their own genetic resources, and the services of farmers in the selection, development, and conservation of their traditional varieties—the foundation on which plant breeding is based—are better recognized. The goals of granting national ownership to genetic resources were to provide incentives for the conservation of diverse germplasm and to address perceived economic inequities between suppliers and demanders of germplasm. This new policy approach is represented by the International Treaty on Plant Genetic Resources for Food and Agriculture, which the U.N. Food and Agricultural Organization approved in November 2001 and which now awaits ratification. This international treaty will govern international exchange of germplasm among countries participating in a multilateral system. Issues of particular interest to developed and developing countries that remain to be resolved, however, include the implementation of benefit sharing, financing conservation, and the list of crops in the system.

Domestic agricultural policies

In many developing countries, the agricultural sector makes an important contribution to the gross national product (GNP). However, domestic policies often penalize agriculture and distort markets, and may be counterproductive in the long run. Farmer and investor choices of technologies and practices are based on prices and costs. If these economic signals are distorted by fiscal or monetary policies, the technology adoption incentives will not be optimal. Market price supports, direct payments to farmers, input subsidies, agricultural taxes, or monetary and trade policies can mask the "true" prices and costs of production and product, thus distorting incentives for the adoption of technology.



Natural Resource Quality and Environmental Sensitivity

A country's natural resource base and environment are crucial factors in determining realistic sustainable agriculture development goals. Although climate and natural disasters are not under a planner's control, the vulnerability to these factors can be mitigated.

There are striking regional differences in cropland quality. Among the countries of Sub-Saharan Africa, an average of 6 percent of cropland has soils and climate that are of high quality for agricultural production. The proportion of high-quality cropland is higher in other regions, ranging from an average of 20 percent among Asian countries, to 28 percent among the countries of Latin America and the Caribbean, and 29 percent among high-income countries. In countries with poor soils and climate, basic inputs such as fertilizer and water are more important than they are in countries that are better endowed.

Given economic and environmental constraints on cropland expansion, the bulk of increased crop production in the future must come from increased yields on existing cropland. In some areas, yield increases may be constrained by soil ero-

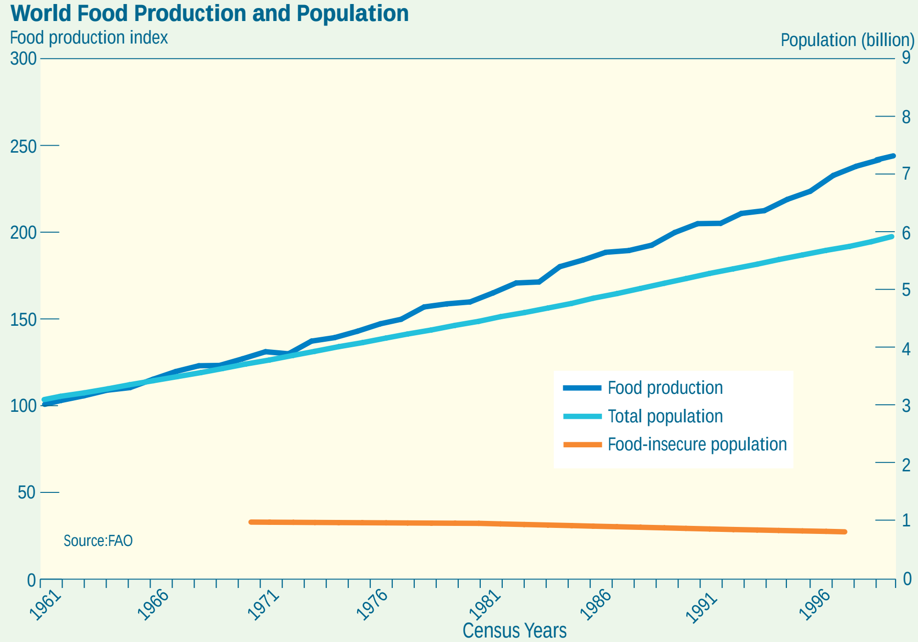
***Land degradation** refers to changes in the quality of soil and water that reduce the ability of land to produce goods and services that people value. Some forms of land degradation, such as nutrient depletion, can be halted and even reversed relatively easily, for example, by appropriate application of fertilizers. Other forms of land degradation, such as erosion or salinization, can be slowed or halted through appropriate management practices, but are generally very costly or time-consuming to reverse.*

Land Quality Affects Agricultural Productivity

Increased resource use and improvements in technology and efficiency have raised global food production more rapidly than population increases in recent decades, but 800 million people remain food insecure. Meanwhile, growth in agricultural productivity appears to be slowing, and land degradation has been blamed as a contributing factor. Estimates of land degradation's impact on productivity vary widely.

Research indicates that land degradation does not threaten productivity growth and food security at the global level. Nevertheless, problems do exist in some areas, especially where fragile resources are found along with poverty and poorly functioning markets and institutions. Recent analysis shows that potential yield losses to soil erosion vary widely by crop and region, but average 0.3 percent per year. Yield losses on such a scale could reverse recent improvements in the number of people who are food insecure. But actual yield losses are likely to be lower to the extent that farmers have incentives to adopt technologies and practices to reduce soil erosion. Also, holding other factors constant, this analysis finds that the productivity of agricultural labor is generally 20-30 percent higher in countries with good soils and climate than it is in countries with poor soils and climate. The quality of labor (measured by literacy and life expectancy), institutions (measured by the absence of armed conflict), and infrastructure (measured by the extent of roads and agricultural research expenditures) also affected agricultural productivity.

World Food Production and Population



Trade liberalization… brings about important transfers of technology, capital investment, and knowledge across borders.

sion and other forms of land degradation. Recent U.S. Department of Agriculture studies show that yield losses (or lack of gains) due to soil erosion vary widely by crop and region, and the losses critically depend on the agricultural practices that are used. To lower these losses, improvements in resource-conserving technologies in some developing countries, and in incentives to farmers to use appropriate practices, may be needed.

In developing countries, increased yields have come at the cost of negative environmental impacts. These impacts may include water pollution, salinization and land abandonment, lowering of groundwater levels, and loss of biodiversity with more uniform crops. However, large areas of environmentally fragile land, which might have been pressed into production had yields not increased in the more favored areas, were saved. Nonetheless, in recent years many developing countries, including those that have benefited the most from the Green Revolution, have been showing signs of a slowdown in agricultural productivity gains. At least part of this slowdown might be attributed to environmental problems related to intensive agriculture. Therefore, greater research emphasis on environmental concerns is increasingly important.

International Agreements and Policies

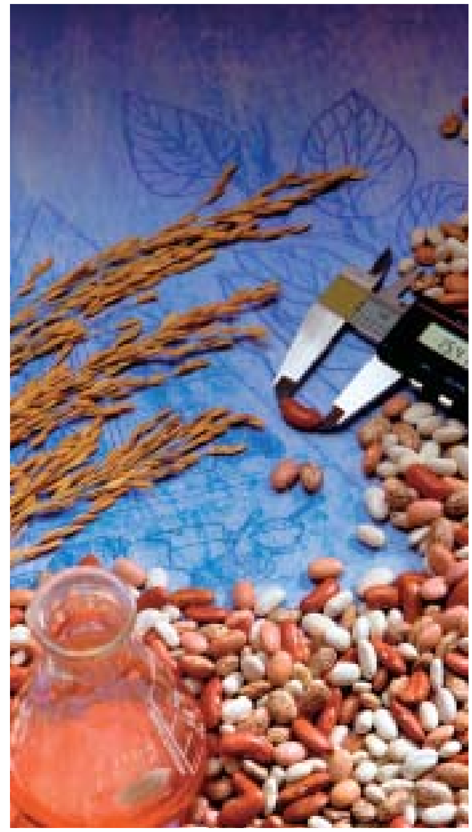
The effectiveness of a country's science and technology policy will depend, to some extent, on international agreements and policies. These international policies are largely out of the control of a single nation, but domestic policy development must take them into account. The complexity of many of these agreements, however, makes it difficult to accurately assess the extent and timing of impacts.

The World Trade Organization (WTO) is a multilateral institution charged with administering transparent rules for global trade among member countries. The WTO fosters trade liberalization that, in turn, brings about important transfers of technology, capital investment, and knowledge across borders. The WTO was established in 1995 as a result of the Uruguay Round, where countries agreed to initiate a more fair and market-oriented agricultural trading system. At the 4th Ministerial in Doha in 2001, WTO members engaged in new multilateral trade negotiations. For agriculture, the Doha Declaration calls for substantial improvements in market access, and the reduction of all forms of export subsidies and trade-distorting domestic support.

The *Agreement on Trade-Related Intellectual Property Rights (TRIPS)* was part of the WTO negotiations, and covers patents, copyrights, trademarks, industrial designs, plant varieties, and trade secrets. Several developing countries expressed the hope that scientific and technological cooperation between developed and developing countries in accordance with the provisions of the TRIPS Agreement would support public interest issues such as health, nutrition, environmental protection, and natural resource conservation in developing countries. Industrialized countries and international organizations were asked to help developing countries implement the TRIPS Agreement by 2006, but national expertise is needed to weigh the benefits and costs of each option. TRIPS will affect the science and technology that will be available to increase productivity.

The *Sanitary and Phytosanitary (SPS) Agreement* established a multilateral mechanism to protect human, animal, and plant health in WTO member countries. SPS measures are required to be based on scientific principles, and the nature and magnitude of the perceived risk must be clearly established. Technologies and practices used in the production of agricultural commodities for trade may be restricted under SPS rules. The science- and research-based requirements of the SPS Agreement can be substantial for a developing country.

The Biosafety Protocol to the United Nations Convention on Biological Diversity provides a regulatory framework for transboundary movements of living bio-engineered organisms. The Protocol requires that regulatory decisions to deny entry of a product in order to avoid or minimize potential adverse effects must be based on risk assessments and sound science. The importation and use of some biotechnology applications may be affected. The Protocol also establishes a biosafety clearinghouse to help countries assess potential risks from genetically engineered organisms. This provision may be useful in addressing the concerns of many countries that believe their current regulatory systems are inadequate to deal with the potential implications of the technology on the nation's environment. Even with a clearinghouse in place, many developing countries will need local expertise to make knowledgeable decisions consistent with national sustainable agriculture goals.



IV

Continuing Opportunities

Scientific breakthroughs and technological innovations in the 20th century fueled substantial gains in agricultural productivity in many developed and developing countries. The development of new technologies and practices resulted from both public and private investments in research. Countries that enjoyed high agricultural productivity growth were able to increase incomes, participate in global markets, reduce hunger and poverty, and improve the quality of life of their citizens.

For the countries that were not able to benefit from the advances in science and technology, agricultural productivity did not grow quickly, which resulted in unmet needs for income growth and food security.

Many technologies and practices developed in the 20th century could be adapted to meet the unique needs of each developing country. Scientific understanding about the interactions between agricultural production and ecosystem health can also contribute to the development of a sustainable agricultural system. The choice of an appropriate set of technologies and practices should incorporate indigenous knowledge of the local economic, social, and natural resource environment.

Agricultural production technologies and practices have been developed to improve soil, water, nutrient, and pest management. Crop improvements contributed to the successes of the Green Revolution. Tools of modern biotechnology have been used to achieve higher levels of stability and sustainability in crop production. These innovations have increased yields and reduced environmental impacts. Advances in animal breeding and health have increased both the quantity and quality of animal protein available to consumers.

Improvements in marketing, processing, and transportation technologies have expanded the choices of food that are readily available to consumers in developed economies. These innovations can be adapted to preserve and deliver vitamin-rich foods to help combat nutrient deficiencies in developing countries. In addition, technologies to reduce food safety hazards can be used to increase the health of both rural and urban populations.

Scientific and technological advances in the 21st century will result from research investments in both traditional agricultural fields and other emerging disciplines. Agricultural production research will be targeted to develop crops and animals that can tolerate a wider range of environmental conditions and offer consumers desired characteristics. Molecular methods will be used to diagnose diseases, locate pollutants in the environment, and detect harmful micro-organisms in food. Modern biotechnology holds promise for the production of pharmaceutical compounds such as vaccines within locally grown plants. Innovations in biological and information sciences have resulted in several emerging fields that hold promise for the development of future agricultural technologies. The new fields of bioremediation, nanotechnology, genomics, proteomics, and bioinformatics will increase knowledge that can be shared and used to improve sustainable agricultural production and protect ecosystem functions in developed and developing countries alike.

Scientific and technological advances hold great promise, but the full benefits of scientific breakthroughs will not be realized without the dissemination and adoption of new technologies. In each country, the successful local development of technologies or the transfer and adaptation of innovations from other countries will depend on incentives and barriers faced by investors and producers. Countries with strong research, health, and education capacity will offer a supportive environment for technology investment. Financial resources are needed to train scientists, enhance and maintain research facilities, develop agricultural markets, and provide adequate health and education systems to the population. External funds could be used to fund these efforts, but the priorities for development must come from within developing countries to ensure that their unique economic, social, and environmental needs are met. Inadequate public utilities, transportation systems, and other infrastructure will impede the development of agricultural markets by limiting the availability of affordable inputs and inhibiting the timely delivery of high-quality agricultural products.

Financial, legal, and political institutions have profound effects on technology development and transfer and on the evolution of agricultural markets. Incentives for domestic and foreign investment are tied to the stability and perceived fairness of the institutional infrastructure within a country. Domestic agricultural policies within developing countries may affect prices and costs, thus distorting incentives for research investment and technology adoption. The sharing of knowledge between countries currently is hindered in some cases by intellectual property rights systems that differ between countries. Innovative public/private partnerships are being designed to help developing countries gain access to new technologies.

It may be difficult to achieve development goals for a sustainable agricultural system in countries that have a poor natural resource base or an environment that is vulnerable to degradation. These conditions limit the choices of technologies and practices that are appropriate to use. In addition to domestic circumstances, international treaties and trade policies have impacts on the success of science and technology policy in developing countries. The liberalization of global trade will affect prices and incentives to invest. The TRIPS Agreement has the potential to enhance the science and technologies that will be available to increase agricultural productivity, and the Biosafety Protocol contains provisions for a clearinghouse to help developing countries make science-based decisions about trade in bio-engineered products. International deliberations can have an effect on decisions regarding investment in technology, even if the country does not actively participate in global markets.

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Scientific and technological advances hold great promise, but the full benefits of scientific breakthroughs will not be realized without the dissemination and adoption of new technologies.

Increasingly, research investments and technology transfer will depend on cooperative endeavors between developed and developing countries and between public and private institutions. Developing countries have many crucial decisions to make in meeting their goals for sustainable agricultural systems. These decisions need to be made and implemented based on the knowledge of each country's unique environmental, social, and economic characteristics. Local expertise is needed to take advantage of indigenous knowledge, and to establish environmental and food safety safeguards to ensure that both the positive and negative potential impacts of a new technology are adequately assessed.

There are many ways that developed countries, international institutions, and businesses can increase the possibilities for developing countries to benefit from scientific and technological advances. They can continue to train scientists and offer the expertise needed to help develop workable plans to achieve productive and sustainable agricultural systems. Investment incentives can be increased directly, and by helping developing countries establish and maintain the legal, financial, transportation, and communications infrastructure necessary to encourage investment.

Public and private investment in research to increase agricultural productivity of the poorest nations can have many benefits. With supportive policy, regulatory, and institutional frameworks in place, science and technology can drive agricultural productivity increases, alleviate hunger, and foster economic growth in developing countries. Incentives for private investment will increase as regions gain the economic resources to participate more actively in the global marketplace. Higher incomes and better nutrition will improve food security and allow more developing countries to share in the growth that many countries have enjoyed for the past half century. Thus, science and technology can play a critical role in helping to prevent famine, improve nutrition, and move countries closer toward a goal of ending world hunger.

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