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

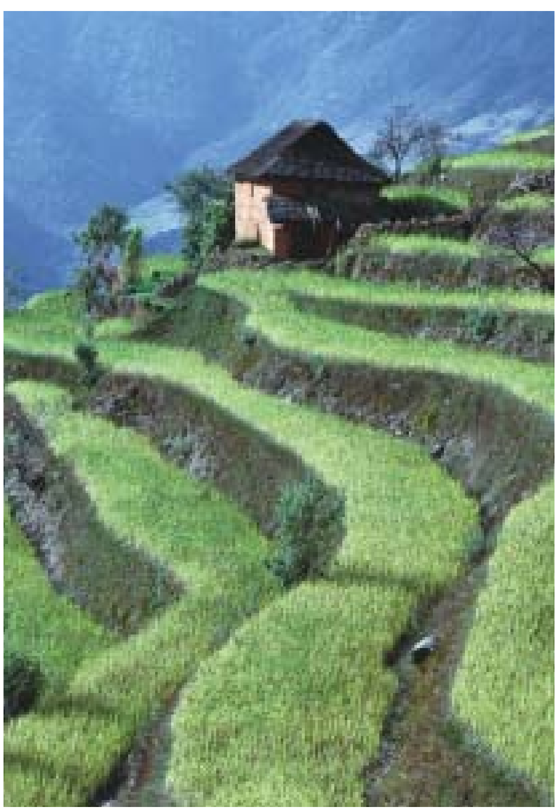
Organic production systems in the United States are managed to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity.

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-

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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

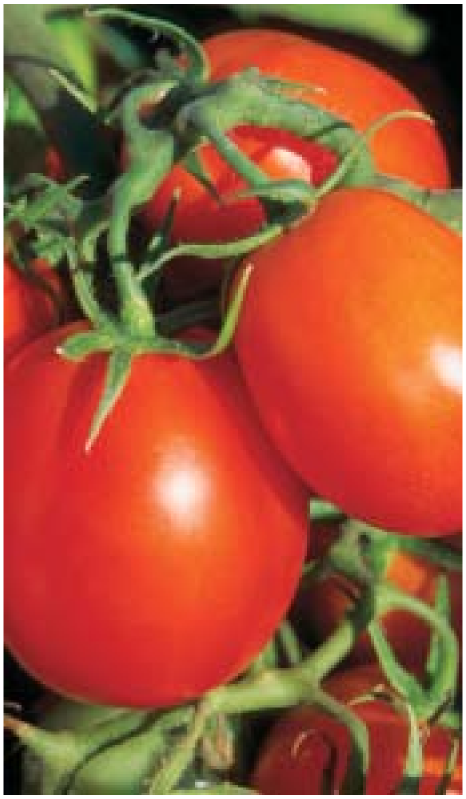
In developed countries, the choices of foods that are readily available to consumers have expanded greatly in the past two decades. Innovations in storage, transportation, processing, and marketing have made the increase in affordable products possible. In these countries, much of the research on postharvest 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.