FIGURE 10-23 Truck farmer, Maine. Specialty fruits such as blueberries are grown in the commercial gardening and fruit farming region along the East Coast of the United States.

KEY ISSUE 4
Why Do Farmers Face Economic Difficulties?

- Challenges for Commercial Farmers
- Challenges for Subsistence Farmers
- Strategies to Increase Food Supply

Commercial and subsistence farmers face comparable challenges. Both commercial and subsistence farmers have difficulty generating enough income to continue farming. The underlying reasons, though, are different. Commercial farmers can produce a surplus of food, whereas many subsistence farmers are barely able to produce enough food to survive.

Challenges for Commercial Farmers

Commercial farmers are in some ways victims of their own success. Having figured out how to produce large quantities of food, they face low prices for their output. Government subsidies help prop up farm income, but many believe that the future health of commercial farming rests with embracing more sustainable practices.

Importance of Access to Markets

Because the purpose of commercial farming is to sell produce off the farm, the distance from the farm to the market influences the farmer’s choice of crop to plant. Geographers use the von Thünen model to help explain the importance of proximity to market in the choice of crops on commercial farms.

Johann Heinrich von Thünen, an estate owner in northern Germany, first proposed the model in 1826 in a book titled The Isolated State (Figure 10-24). According to the model, which was later modified by geographers, a commercial farmer initially considers which crops to cultivate and which animals to raise based on market location. In choosing an enterprise, the farmer compares two costs—the cost of the land versus the cost of transporting products to market.

von Thünen based his general model of the spatial arrangement of different crops on his experiences as owner of a large estate in northern Germany during the early nineteenth century. He found that specific crops were grown in different rings around the cities in the area. Market-oriented gardens and milk producers were located in the first ring out from the cities. These products are expensive to deliver and must reach the market quickly because they are perishable. The next ring out from the cities contained wood lots, where timber was cut for construction and fuel; closeness to market is important for this commodity because of its weight.
Europe and North America, for example, are less likely to grow highly perishable and bulky products.

**Overproduction in Commercial Farming**

Commercial farmers suffer from low incomes because they are capable of producing much more food than is demanded by consumers in MDCs. A surplus of food can be produced because of widespread adoption of efficient agricultural practices. New seeds, fertilizers, pesticides, mechanical equipment, and management practices have enabled farmers to obtain greatly increased yields per area of land. The experience of dairy farming in the United States demonstrates the growth in productivity. The number of milk cows in the United States decreased from 10.8 million to 9.3 million between 1980 and 2008. But milk production increased from 128 billion to 190 billion pounds—yield per cow thus nearly doubled in the period.

Although the food supply has increased in MDCs, demand has remained constant, because the market for most products is already saturated. In MDCs, consumption of a particular commodity may not change significantly if the price changes. Americans, for example, do not switch from Wheaties to Corn Flakes if the price of corn falls more rapidly than wheat. Demand is also stagnant for most agricultural products in MDCs because of low population growth.

The U.S. government has three policies that are supposed to address the problem of excess productive capacity:

1. **Farmers are encouraged to avoid producing crops that are in excess supply.** Because soil erosion is a constant threat, the government encourages planting fallow crops, such as clover, to restore nutrients to the soil and to help hold the soil in place. These crops can be used for hay, forage for pigs, or to produce seeds for sale.

2. **The government pays farmers when certain commodity prices are low.** The government sets a target price for the commodity and pays farmers the difference between the price they receive in the market and a target price set by the government as a fair level for the commodity. The target prices are calculated to give farmers the same price for the commodity today as in the past, when compared to other consumer goods and services.

3. **The government buys surplus production and sells or donates it to foreign governments.** In addition, low-income Americans receive food stamps in part to stimulate their purchase of additional food.

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**FIGURE 10-24** (left) Von Thünen model of the role of situation factors in choice of crop. According to the von Thünen model, in the absence of topographic factors, different types of farming are conducted at different distances from a city, depending on the cost of transportation and the value of the product. (right) Von Thünen recognized that his model would be modified by site factors, such as a river in this sketch, which changes the accessibility of different land parcels to the market center. Agricultural uses that seek highly accessible locations need to locate nearer the river. The following example illustrates the influence of transportation cost on the profitability of growing wheat:

1. **Gross profit from sale of wheat grown on 1 hectare of land not including transportation costs:**
   a. Wheat can be grown for $0.25 per kilogram.
   b. Yield per hectare of wheat is 1,000 kilograms.
   c. Gross profit is $250 per hectare ($0.25 per kilogram × 1,000 kilograms per hectare).

2. **Net profit from sale of wheat grown on 1 hectare of land including transportation costs:**
   a. Cost of transporting 1,000 kilograms of wheat to the market is $62.50 per kilometer.
   b. Net profit from the sale of 1,000 kilograms of wheat grown on a farm located 1 kilometer from the market is $187.50 ($250 gross profit – $62.50 per kilometer transport costs).
   c. Net profit from sale of 1,000 kilograms of wheat grown on a farm located 4 kilometers from the market is $0 ($250 gross profit – $62.50 per kilometer × 4 kilometers).

The example shows that a farmer would make a profit growing wheat on land located less than 4 kilometers from the market. Beyond 4 kilometers, wheat is not profitable because the cost of transporting it exceeds the gross profit. These calculations demonstrate that farms located closer to the market tend to select crops with higher transportation costs per hectare of output, whereas more distant farms are more likely to select crops that can be transported less expensively.
The United States has averaged about $16 billion a year on farm subsidies in recent years. Annual spending varies considerably from one year to the next: Subsidy payments are lower in years when market prices rise and production is down, typically as a result of poor weather conditions in the United States or political problems in other countries. Farming in Europe is subsidized even more than in the United States. More farmers receive subsidies in Europe, and they receive more than American farmers. The high subsidies are a legacy of a long-standing commitment by the European Union to maintain agriculture in its member states, especially in France. Supporters point to the preservation of rural village life in parts of Europe, while critics charge that Europeans pay needlessly high prices for food as a result of the subsidies.

Government policies in MDCs point out a fundamental irony in worldwide agricultural patterns. In an MDC such as the United States, farmers are encouraged to grow less food, whereas LDCs struggle to increase food production to match the rate of growth in the population.

Sustainable Agriculture

Some commercial farmers are converting their operations to sustainable agriculture, an agricultural practice that preserves and enhances environmental quality (Figure 10-25). Farmers practicing sustainable agriculture typically generate lower revenues than do conventional farmers, but they also have lower costs.

An increasingly popular form of sustainable agriculture is organic farming. However, some organic farms, especially the larger ones, may rely in part on nonsustainable practices, such as use of fossil fuels to operate tractors. Worldwide, 32.2 million hectares (79 million acres), or 0.24 percent of farmland, was classified as organic in 2007. Australia was the leader, with 12 million of the hectares, or 37 percent of the worldwide total. Argentina, Brazil, the United States, China, Italy, India, Spain, Uruguay, and Germany together accounted for 40 percent of the worldwide total.

Three principal practices distinguish sustainable agriculture (and at its best, organic farming) from conventional agriculture:

- Sensitive land management
- Limited use of chemicals
- Better integration of crops and livestock

**SENSITIVE LAND MANAGEMENT.** Sustainable agriculture protects soil in part through ridge tillage, which is a system of planting crops on ridge tops. Crops are planted on 10-to 20-centimeter (4- to 8-inch) ridges that are formed during cultivation or after harvest. The crop is planted on the same ridges, in the same rows, year after year. Ridge tillage is attractive for two main reasons—lower production costs and greater soil conservation.

Production costs are lower with ridge tillage in part because it requires less investment in tractors and other machinery than conventional planting. An area that would be prepared for planting under conventional farming with three to five tractors can be prepared for ridge tillage with only one or two tractors. The primary tillage tool is a row-crop cultivator that can form ridges. There is no need for a plow, or field cultivator, or a 300-horsepower four-wheel-drive tractor. With ridge tillage, the space between rows needs to match the distance between wheels of the machinery. If 75 centimeters (30 inches) are left between rows, tractor tires will typically be on 150-centimeter (60-inch) centers and combine wheels on 300-centimeter (120-inch) centers. Wheel spacers are available from most manufacturers to fit the required spacing.

Ridge tillage features a minimum of soil disturbance from harvest to the next planting. A compaction-free zone is created under each ridge and in some row middles. Keeping the trafficked area separate from the crop-growing area improves soil properties. Over several years the soil will tend to have increased organic matter, greater water-holding capacity and more earthworms. The channels left by earthworms and decaying roots enhance drainage.

Ridge tillage compares favorably with conventional farming for yields while lowering the cost of production. Although more labor-intensive than other systems, it is profitable on a per-acre basis. In Iowa, for example, ridge tillage has gained favor for production of organic and herbicide-free soybeans, which sell for more than regular soybeans.

**LIMITED USE OF CHEMICALS.** In conventional agriculture, seeds are often genetically modified to survive when herbicides and insecticides are sprayed on
GLOBAL FORCES, LOCAL IMPACTS
Genetically Modified Foods and Sub-Saharan Africa

Sub-Saharan African countries have been urged by the United States to increase their food supply in part through increased use of genetic modification (GM) of crops and livestock (Figure 10-26). Africans are divided on whether to accept GM organisms.

Farmers have been manipulating crops and livestock for thousands of years: The very nature of agriculture is to deliberately manipulate nature. Humans control selective reproduction of plants and animals in order to produce a larger number of stronger, hardier survivors. Beginning in the nineteenth century, the science of genetics expanded understanding of how to manipulate plants and animals to secure dominance of the most favorable traits. However, GM, which became widespread in the late twentieth century, marks a sharp break with the agricultural practices of the past several thousand years. Under GM the genetic composition of an organism is not merely studied, it is actually altered, for GM involves mixing genetic material of two or more species that would not otherwise mix in nature.

GM is especially widespread in the United States: 89 percent of soybeans, 83 percent of cotton, and 61 percent of maize; three-fourths of the processed food that Americans consume has at least one GM ingredient. Worldwide, 102 million hectares of farmland were devoted to GM in 2006, three times more land than was devoted to organic farming. The United States was responsible for 53 percent of the world’s GM crops in 2006, and Canada another 6 percent. Argentina was second to the United States, accounting for 18 percent of the world’s GM crops.

Africans must weigh arguments both for and against adoption of GM. The positives of GM are higher yields, increased nutrition, and more resistance to pests. GM foods are also better tasting, at least to some palates. Despite these benefits, opposition to GM is strong in Africa for several reasons:

- **Health problems.** Consuming large quantities of GM may reduce the effectiveness of antibiotics and could destroy long-standing ecological balances in local agriculture.
- **Export problems.** European countries, the main markets for Africa’s agricultural exports, require GM foods to be labeled. Europeans are especially strongly opposed to GM because they believe the food is not as nutritious as that from traditionally bred crops and livestock. Because European consumers shun GM food, African farmers fear that if they are no longer able to certify their exports as GM-free, European customers will stop buying them.
- **Increased dependence on the United States.** U.S.-based transnational corporations, such as Monsanto, manufacture most of the GM seeds. Africans fear that the biotech companies could—and would—introduce a so-called “terminator” gene in the GM seeds, to prevent farmers from replanting them after harvest and require them to continue to purchase seeds year after year from the transnational corporations.

“We don’t want to create a habit of using genetically modified maize that the country cannot maintain,” explained Mozambique’s prime minister. If agriculture is regarded as a way of life, not just a food production business, GM represents for many Africans an unhealthy level of dependency on MDCs.

**FIGURE 10-26** Genetically modified potatoes may not be sold in Japan.

Aside from adverse impacts on soil and water quality, widespread use of “Roundup-Ready” seeds is causing some weeds to become resistant to the herbicide.

Sustainable agriculture, on the other hand, involves application of limited if any herbicides to control weeds. In principle, farmers can control weeds without chemicals, although it requires additional time and expense that few farmers can
afford. Researchers have found that combining mechanical weed control with some chemicals yields higher returns per acre than relying solely on one of the two methods.

Ridge tilling also promotes decreased use of chemicals, which can be applied only to the ridges and not the entire field. Combining herbicide banding—which applies chemicals in narrow bands over crop rows—with cultivating may be the best option for many farmers.

**INTEGRATED CROP AND LIVESTOCK.** Sustainable agriculture attempts to integrate the growing of crops and the raising of livestock as much as possible at the level of the individual farm. Animals consume crops grown on the farm and are not confined to small pens. In conventional farming, integration between crops and livestock generally takes place through intermediaries rather than inside an individual farm. As discussed earlier in the chapter, mixed crop and livestock is a common form of farming in many LDCs and in the Corn Belt of the United States. But many farmers in the mixed crop and livestock region actually choose to only grow crops or raise more animals than the crops they grow can feed. They sell their crops off the farm or purchase feed for their animals from outside suppliers. Integration of crops and livestock reflects a return to the historical practice of mixed crop and livestock farming, in which growing crops and raising animals were regarded as complementary activities on the farm. This was the common practice for centuries until the mid-1900s when technology, government policy, and economics encouraged farmers to become more specialized.

Sustainable agriculture is sensitive to the complexities of biological and economic interdependencies between crops and livestock:

1. **Number of livestock.** The correct number, as well as the distribution, of livestock for an area is determined based on the landscape and forage sources. Prolonged concentration of livestock in a specific location can result in permanent loss of vegetative cover, so the farmer needs to move the animals to reduce overuse in some areas. Growing row crops on the more level land while confining pastures to steeper slopes will reduce soil erosion, so it may be necessary to tolerate some loss of vegetation in specific locations. The farmer may need to balance the need to secure livestock inside fences with the convenience of tilling large unfenced fields through the use of temporary fencing.

2. **Animal confinement.** The moral and ethical debate over animal welfare is particularly intense regarding confined livestock production systems. Confined livestock are a source of surface and ground water pollutants, particularly where the density of animals is high. Expensive waste management facilities are a necessary cost of confined production systems. If animals are not confined, manure can contribute to soil fertility. However, quality of life in nearby communities may be adversely affected by the smell.

3. **Management of extreme weather conditions.** Herd size may need to be reduced during periods of short- and long-term droughts. On the other hand, livestock can buffer the negative impacts of low rainfall periods by consuming crops that in conventional farming would be left as failures. Especially in Mediterranean climates such as California’s, properly managed grazing significantly reduces fire hazards by reducing fuel buildup in grasslands and brushlands.

4. **Flexible feeding and marketing.** This can help cushion farmers against trade and price fluctuations and, in conjunction with cropping operations, make more efficient use of farm labor. Feed costs are the largest single variable cost in any livestock operation. Most of the feed may come from other enterprises on the ranch, though some is usually purchased off the farm. Feed costs can be kept to a minimum by monitoring animal condition and performance and understanding seasonal variations in feed and forage quality on the farm.

**Challenges for Subsistence Farmers**

Two issues discussed in earlier chapters influence the choice of crops planted by subsistence farmers:

- Subsistence farmers must feed an increasing number of people because of rapid population growth in LDCs (discussed in Chapter 2).
- Subsistence farmers must grow food for export instead of for direct consumption due to the adoption of the international trade approach to development (discussed in Chapter 9).

**Subsistence Farming and Population Growth**

Population growth influences the distribution of types of subsistence farming, according to economist Ester Boserup. It compels subsistence farmers to consider new farming approaches that produce enough food to take care of the additional people.

For hundreds if not thousands of years, subsistence farming in LDCs yielded enough food for people living in rural villages to survive, assuming no drought, flood, or other natural disaster occurred. Suddenly in the late twentieth century, the LDCs needed to provide enough food for a rapidly increasing population as well as for the growing number of urban residents who cannot grow their own food. According to Boserup, subsistence farmers increase the supply of food through intensification of production, achieved in two ways:

1. **Adoption of new farming methods.** Plows replace axes and sticks. More weeding is done, more manure applied, more terraces carved out of hillsides, and more irrigation ditches dug. The additional labor needed to perform these operations comes from the population growth. The farmland yields more food per area of land, but with the growing population, output per person remains about the same.
2. Land is left fallow for shorter periods. This expands the amount of land area devoted to growing crops at any given time. Boserup identified five basic stages in the intensification of farmland:

- **Forest Fallow.** Fields are cleared and utilized for up to 2 years and left fallow for more than 20 years, long enough for the forest to grow back.
- **Bush Fallow.** Fields are cleared and utilized for up to 8 years and left fallow for up to 10 years, long enough for small trees and bushes to grow back.
- **Short Fallow.** Fields are cleared and utilized for perhaps 2 years (Boserup was uncertain) and left fallow for up to 2 years, long enough for wild grasses to grow back.
- **Annual Cropping.** Fields are used every year and rotated for a few months with planting legumes and roots.
- **Multicropping.** Fields are used several times a year and never left fallow.

Contrast shifting cultivation, practiced in regions of low population density, such as central Africa, with intensive subsistence agriculture, practiced in regions of high population density, such as East Asia. Under shifting cultivation, cleared fields are utilized for a couple of years, then left fallow for 20 years or more. This type of agriculture supports a small population living at low density. As the number of people living in an area increases (that is, the population density increases) and more food must be grown, fields will be left fallow for shorter periods of time. Eventually, farmers achieve the very intensive use of farmland characteristic of areas of high population density.

**Subsistence Farming and International Trade**

To expand production, subsistence farmers need higher-yield seeds, fertilizer, pesticides, and machinery. Some needed supplies can be secured by trading food with urban dwellers. For many African and Asian countries, though, the main way to obtain agricultural supplies is to import them from other countries. However, they lack the money to buy agricultural equipment and materials from MDCs.

To generate the funds they need to buy agricultural supplies, LDCs must produce something they can sell in MDCs. The LDCs sell some manufactured goods (see Chapter 11), but most raise funds through the sale of crops in MDCs. Consumers in MDCs are willing to pay high prices for fruits and vegetables that would otherwise be out of season or for crops such as coffee and tea that cannot be grown in MDCs because of the climate.

In an LDC such as Kenya, families may divide by gender between traditional subsistence agriculture and contributing to international trade. Women practice most of the subsistence agriculture—that is, growing food for their families to consume—in addition to the tasks of cooking, cleaning, and carrying water from wells. Men may work for wages, either growing crops for export or at jobs in distant cities. Because men in Kenya frequently do not share the wages with their families, many women try to generate income for the household by making clothes, jewelry, baked goods, and other objects for sale in local markets.

The sale of export crops brings an LDC foreign currency, a portion of which can be used to buy agricultural supplies. But governments in LDCs face a dilemma: The more land that is devoted to growing export crops, the less that is available to grow crops for domestic consumption. Rather than helping to increase productivity, the funds generated through the sale of export crops may be needed to feed the people who switched from subsistence farming to growing export crops.

**Drug Crops**

The export crops chosen in some LDCs, especially in Latin America and Asia, are those that can be converted to drugs. Marijuana, the most popular drug, is estimated to be used by 140 million worldwide. Cocaine and heroin, the two leading, especially dangerous drugs, are abused by 15 million and 14 million people, respectively, worldwide. The United Nations estimated that in 1998 the incomes of 4 million people, primarily in Asia and Latin America, were dependent on cultivation of the opium poppy or coca leaf (Figure 10-27).

![FIGURE 10-27 Drug trade. Most of the world's opium comes from Afghanistan, and most of the world's cocaine originates in Colombia.](image-url)
Heroin is derived from raw opium gum, which is produced by the opium poppy plant. Afghanistan is the source of around 80 percent of the world’s opium; most of the remainder is grown in Myanmar (Burma). Most consumers are located in Central Asia. One-half of the world’s coca leaf is grown in Columbia, and most of the remainder in neighboring Peru and Bolivia. Most of the processing of cocaine, as well as its distribution to the United States and other MDCs, is based in Columbia. Marijuana, produced from the Cannabis sativa plant, is cultivated widely around the world. The overwhelming majority of the marijuana that reaches the United States is grown in Mexico. Cultivation of C. sativa is not thought to be expanding worldwide, whereas opium poppies and coca leaf are.

Strategies to Increase the Food Supply

Four strategies are being employed to increase the world’s food supply:

- Expanding the land area used for agriculture
- Increasing the productivity of land now used for agriculture
- Identifying new food sources
- Increasing exports from other countries

Challenges underlie each of these strategies.

Expanding Agricultural Land

Historically, world food production has increased primarily by expanding the amount of land devoted to agriculture (Figure 10-28). When the world’s population began to increase more rapidly in the late eighteenth and early nineteenth centuries, during the Industrial Revolution, pioneers could migrate to uninhabited territory and cultivate the land. Sparsely inhabited land suitable for agriculture was available in western North America, central Russia, and Argentina’s pampas.

Two centuries ago people believed that good agricultural land would always be available for willing pioneers. Today few scientists believe that further expansion of agricultural land can feed the growing world population. At first glance, new agricultural land appears to be available because only 11 percent of the world’s land area is currently cultivated. In fact, cultivated land has been expanding in Africa at a rate of 1 percent per year. But population in Africa is increasing more than 2 percent per year. Worldwide, despite the recent decline in the natural increase, agricultural land is expanding more slowly than population.

In some regions, farmland is abandoned for lack of water (Figure 10-29). Especially in semiarid regions, human actions are causing land to deteriorate to a desertlike condition, a process called desertification (more precisely, semiarid land degradation). Semiarid lands that can support only a handful of pastoral nomads are overused because of rapid population growth. Excessive crop planting, animal grazing, and tree cutting exhaust the soil’s nutrients and preclude agriculture. The Earth Policy Institute estimates that 2 billion hectares (5 million acres) of land have been degraded around the world. Overgrazing is thought to be responsible for 34 percent of the total, deforestation for 30 percent, and agricultural use for 28 percent. The United Nations estimates that desertification removes 27 million hectares (70 million acres) of land from agricultural production each year, an area roughly equivalent to Colorado.

Excessive water threatens other agricultural areas, especially drier lands that receive water from human-built irrigation systems. If the irrigated land has inadequate drainage, the underground water level rises to the point where roots become waterlogged. The United Nations estimates that 10 percent of all irrigated land is waterlogged, mostly in Asia and South America. If the water is salty, it can damage plants. The ancient civilization of Mesopotamia may have collapsed in part because of waterlogging and excessive salinity in its agricultural lands near the Tigris and Euphrates rivers.

Urbanization can also contribute to reducing agricultural land. As urban areas grow in population and land area, farms on the periphery are replaced by homes, roads, shops, and other urban land uses. In North America, farms outside urban areas are left idle until the speculators who own them can sell them at a profit to builders and developers, who convert the land to urban uses.

Increasing Productivity

Population grew at the fastest rate in human history during the second half of the twentieth century, as discussed in Chapter 2. Many experts forecast massive global famine, but these dire predictions did not come true. New agricultural practices have permitted farmers worldwide to achieve...
much greater yields from the same amount of land. The invention and rapid diffusion of more productive agricultural techniques during the 1970s and 1980s is called the green revolution. The green revolution involves two main practices—the introduction of new higher-yield seeds and the expanded use of fertilizers. Because of the green revolution, agricultural productivity at a global scale has increased faster than population growth.

Scientists began an intensive series of experiments during the 1950s to develop a higher-yield form of wheat (Figure 10-30). A decade later, the “miracle wheat seed” was ready. Shorter and stiffer than traditional breeds, the new wheat was less sensitive to variation in day length, responded better to fertilizers, and matured faster. The Rockefeller and Ford foundations sponsored many of the studies, and the program’s director, Dr. Norman Borlaug, won the Nobel Peace Prize in 1970. The International Rice Research Institute, established in the Philippines by the Rockefeller and Ford foundations, worked to create a miracle rice seed. During the 1960s, their scientists introduced a hybrid of Indonesian rice and Taiwan dwarf rice that was hardier and that increased yields. More recently, scientists have developed new high-yield maize (corn).

The new miracle seeds were diffused rapidly around the world. India’s wheat production, for example, more than doubled in 5 years. After importing 10 million tons of wheat annually in the mid-1960s, India by 1971 had a surplus of several million tons. Other Asian and Latin American countries recorded similar productivity increases. The green revolution was largely responsible for preventing a food crisis in these regions during the 1970s and 1980s. But will these scientific breakthroughs continue in the twenty-first century?

To take full advantage of the new miracle seeds, farmers must use more fertilizer and machinery. Farmers have known for thousands of years that application of manure, bones, and ashes somehow increases, or at least maintains, the fertility of the land. Not until the nineteenth century did scientists...
identify nitrogen, phosphorus, and potassium (potash) as the critical elements in these substances that improved fertility. Today these three elements form the basis for fertilizers—products that farmers apply to their fields to enrich the soil by restoring lost nutrients.

Nitrogen, the most important fertilizer, is a ubiquitous substance. China is the leading producer of nitrogen fertilizer. Europeans most commonly produce a fertilizer known as urea, which contains 46 percent nitrogen. In North America, nitrogen is available as ammonia gas, which is 82 percent nitrogen but more awkward than urea to transport and store. Both urea and ammonia gas combine nitrogen and hydrogen. The problem is that the cheapest way to produce both types of nitrogen-based fertilizers is to obtain hydrogen from natural gas or petroleum. As fossil-fuel prices increase, so do the prices for nitrogen-based fertilizers, which then become too expensive for many farmers in LDCs. In contrast to nitrogen, phosphorus and potash reserves are not distributed uniformly across Earth’s surface. Phosphate rock reserves are clustered in China, Morocco, and the United States. Proven potash reserves are concentrated in Canada, Russia, and Ukraine.

Farmers need tractors, irrigation pumps, and other machinery to make the most effective use of the new miracle seeds. In LDCs, farmers cannot afford such equipment and cannot, in view of high energy costs, buy fuel to operate the equipment. To maintain the green revolution, governments in LDCs must allocate scarce funds to subsidize the cost of seeds, fertilizers, and machinery.

**Identifying New Food Sources**

A third alternative for increasing the world’s food supply is to develop new food sources. Three strategies being considered are to cultivate the oceans, to develop higher-protein cereals, and to improve palatability of rarely consumed foods.

**CULTIVATING OCEANS.** At first glance, increased use of food from the sea is attractive. Oceans are vast, covering nearly three-fourths of Earth’s surface and lying near most population concentrations. Historically the sea has provided only a small percentage of the world food supply. About two-thirds of the fish caught from the ocean is consumed directly, whereas the remainder is converted to fish meal and fed to poultry and hogs.

Hope grew during the mid-twentieth century that increased fish consumption could meet the needs of a rapidly growing global population. Indeed, the world’s annual fish catch increased from around 30 million tons in 1950 to 100 million tons in 1990. However, the population of some fish species declined because they were harvested faster than they could reproduce. Overfishing has been particularly acute in the North Atlantic and Pacific oceans. Because of overfishing, the population of large predatory fish, such as tuna and swordfish, declined by 90 percent in the past half-century. The United Nations estimates that one-quarter of fish stocks have been overfished and one-half fully exploited, leaving only one-fourth underfished. Consequently, the total world fish catch has remained relatively constant since the 1980s despite population growth (Figure 10-31).

To protect fishing areas, many countries have claimed control of the oceans within 200 nautical miles of the coast. These countries have the right to seize foreign fishing vessels that venture into the so-called exclusive economic zone.

**DEVELOPING HIGHER-PROTEIN CEREALS.** A second possible new food source is higher-protein cereal grains. People in MDCs obtain protein by consuming meat, but people in LDCs generally rely on wheat, corn, and rice, which lack certain proteins. Scientists are experimenting with hybrids of the world’s major cereals that have higher protein content. People can also obtain needed nutrition by consuming foods that are fortified during processing with vitamins, minerals, and protein-carrying amino acids. This approach achieves better nutrition without changing food-consumption habits. However, fortification has limited application in LDCs, where most people grow their own food rather than buy processed food.

**IMPROVING PALATABILITY OF RARELY CONSUMED FOODS.** To fulfill basic nutritional needs, people consume types of food adapted to their community’s climate, soil, and other physical characteristics. People also select foods on the basis of religious values, taboos, and other social customs that are unrelated to nutritional or environmental factors. A third way to make more effective use of existing global resources is to encourage consumption of foods that are avoided for social reasons.

A prominent example of an underused food resource in North America is the soybean. Although the soybean is one of the region’s leading crops, most of the output is processed into animal feed, in part because many North Americans avoid consuming tofu, sprouts, and other recognizable soybean

![Figure 10-31](image-url)
products. However, burgers, franks, oils, and other products that are made from soybeans but do not look like soybeans are more widely accepted in North America. New food products have been created in LDCs as well. In Asia, for example, high-protein beverages made from seeds resemble popular soft drinks.

Krill (a term for a group of small crustaceans) could be an important source of food from the oceans. The krill population has increased rapidly in recent years, because overhunting has reduced the number of whales that eat krill. The Soviet Union was a major harvester of krill, used primarily to feed chickens and livestock. Since the breakup of the Soviet Union in the early 1990s, the world krill harvest has declined substantially. Because krill deteriorates rapidly new processing methods could substantially increase the harvest for human food; unfortunately, krill does not taste very good.

Increasing Trade

A fourth alternative for increasing the world’s food supply is to export more food from countries that produce surpluses (Figure 10-32). The three top export grains are wheat, maize (corn), and rice. Few countries are major exporters of food, but increased production in these countries could cover the gap elsewhere.

Before World War II, Western Europe was the only major grain-importing region. Prior to their independence, colonies of Western European countries supplied food to their parent states. Asia became a net grain importer in the 1950s, Africa and Eastern Europe in the 1960s, and Latin America in the 1970s. Population increases in these regions largely accounted for the need to import grain. By 1980 North America was the only major exporting region in the world. In response to the increasing global demand for food imports, the United States passed Public Law 480, the Agricultural, Trade, and Assistance Act of 1954 (frequently referred to as “P.L.-480”). Title I of the act provided for the sale of grain at low interest rates, and Title II gave grants to needy groups of people. The United States remains the world’s leading exporter of grain by a wide margin, accounting for one-third of the total exports of the three leading grains, including more than one-half of all maize exports and more than one-fourth of all wheat exports.

Elsewhere in the world the picture has changed in the twenty-first century. From net importers of grain, South Asia and Southeast Asia have now become net exporters. Thailand has replaced the United States as the leading exporter of rice, accounting for one-third of the world total, followed by India in second place with one-sixth. Vietnam and Pakistan ranked fourth and fifth, respectively, in rice exports in 2004, behind the United States in third place. Japan is by far the world’s leading grain importing country, followed by China. Japan is the leading importer of maize and China of wheat, and both rank among leading rice importers. On a regional scale, Southwest Africa (with Northern Africa) has become the leading net importer of all three major grains, and Saudi Arabia was the world’s leading importer of rice in 2007. Sub-Saharan Africa also ranks among the leaders in net imports of all three grains.