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Agriculture, Biotechnology, and the Future of Food

Chapter Objectives

This chapter will help students:

- Explain the challenge of feeding a growing human population
- Identify the goals, methods, and consequences of the Green Revolution
- Describe approaches for preserving crop diversity
- Categorize strategies for pest management
- Discuss the importance of pollination
- Describe the science behind genetically modified food
- Evaluate the debate over genetically modified food
- Assess feedlot agriculture for livestock and poultry
- Weigh approaches in aquaculture
- Evaluate sustainable agriculture

Lecture Outline

I. Central Case: Possible Transgenic Maize in Southern Mexico

A. Corn is a staple grain of the world's food supply. Southern Mexico is a world center of biodiversity for maize, with many locally adapted domesticated varieties, called landraces.

B. In 2001, Mexican scientists found DNA in Oaxacan farmers' maize that seemed to match genes from genetically modified corn.

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1. To genetically engineer crops, scientists extract genes from the DNA of one organism and transfer them into the DNA of another organism of a different species.
2. The genes are called transgenes, and the new organisms are transgenic plants.

C. Two researchers collected samples of wild maize and their lab analyses revealed traces of DNA from genetically engineered corn.

D. Their findings were published in *Nature,* but the findings were disputed and, bowing to criticism, *Nature* stated that the study should never have been published.

E. Further research has confirmed their findings.

F. The question is how (positively and negatively) genetically modified crops may affect people and the environment.

II. The Race to Feed the World

A. We are producing more food per person.

1. We have increased food production by devoting more fossil fuel energy to agriculture; intensifying our use of irrigation, fertilizers, and pesticides; planting and harvesting more frequently; cultivating more land; and developing (through crossbreeding and genetic engineering) more productive crop and livestock varieties.

B. We face undernutrition, overnutrition, and malnutrition.

1. People suffer from undernutrition, receiving fewer calories than the minimum dietary energy requirement. Most people who are undernourished live in the developing world.
2. Agricultural scientists and policymakers pursue a goal of food security, the guarantee of an adequate, reliable, and available food supply to all people at all times.
3. Those who suffer from overnutrition receive too many calories each day.
4. The quality of food is important as well. Malnutrition is a shortage of nutrients the body needs, and it can occur in both undernourished and overnourished individuals.

C. The Green Revolution boosted agricultural production.

1. Realizing that farmers could not go on forever cultivating additional land to increase crop output, agricultural scientists devised methods and technologies to increase crop output per unit area of existing cultivated land, called the Green Revolution.

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2. Many people saw such growth in production and efficiency as key to ending starvation in developing nations.
3. The transfer of technology to the developing world began in 1940 when a specially bred wheat species was introduced to Mexico.
4. Soon many developing countries were doubling, tripling, or quadrupling their yields using selectively bred strains of wheat, rice, corn, and other crops from industrialized nations.

D. The Green Revolution brought mixed consequences.

1. Developing countries imported the methods of industrialized agriculture such as the use of synthetic fertilizers, chemical pesticides, irrigation, and heavy equipment.
2. This high-input agriculture was dramatically successful at allowing farmers to harvest more corn, wheat, rice, and soybeans from each hectare of land.
3. Between 1961 and 2008, food production rose 150% and population rose 100%, while area converted for agriculture increased only 10%.
4. Green revolution techniques have had negative consequences for biodiversity and mixed consequences for crop yields. The intensive use of water, fossil fuels, and chemical fertilizers and pesticides has had extensive negative impacts in terms of pollution, salinization, and desertification.
5. The planting of monocultures, large expanses of single-crop types, has made planting and harvesting more efficient, but has reduced biodiversity and increased the susceptibility of entire crops to disease, pathogens, and insect pests. This brings the risk of catastrophic failure.
6. Monocultures have also contributed to a narrowing of the human diet. This has nutritional and biodiversity dangers.

E. Biofuels affect food supplies.

1. Biofuels are fuels derived from organic materials. They are used in internal combustion engines as replacements for petroleum.
   a. In the United States, ethanol made from corn is the primary biofuel.
2. The world realized belatedly that growing crops for biofuels could compete directly with growing food for people to eat.

III. Preserving Crop Diversity

A. Crop diversity insures against failure.

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1. Because accidental interbreeding can diminish the diversity of local variants, many scientists argue that we need to protect landraces in areas that remain important repositories of crop biodiversity, as in southern Mexico.
2. Over the past century, we have already lost a great deal of genetic diversity in crops worldwide.

B. Seed banks are living museums.

1. The most renowned seed bank is the so-called "doomsday seed vault" that opened in 2008 on the island of Spitsbergen in Arctic Norway. The internationally funded Svalbard Global Seed Vault is storing millions of seeds from around the world (spare sets from other seed banks) as a safeguard against global agricultural calamity—"an insurance policy for the world's food supply.

IV. Pests and Pollinators

A. We have developed thousands of chemical pesticides.

1. Throughout the history of agriculture, pests have taken advantage of our clustering of food plants into agricultural fields.
2. A *pest* is any organism that damages crops that are valuable to us. A *weed* is any plant that competes with our crops. These are subjective categories defined entirely by our own economic interests.
3. Poisons that target pest organisms are called pesticides. Over 900 million pounds of the active ingredients of pesticides are applied in the United States each year.

B. Pests evolve resistance to pesticides.

1. Industrial chemists are caught up in an evolutionary arms race with the pests they battle, racing to increase or retarget the toxicity of their chemicals while the armies of pests evolve ever-stronger resistance to their efforts.
2. Pesticides often kill non-target organisms, including the predators and parasites of the pests. When these valuable natural enemies are eliminated, pest populations become that much harder to control.

C. Biological control pits one organism against another.

1. Biological control, or biocontrol, operates on the principle that "the enemy of one's enemy is one's friend." We find natural enemies, or predators, of a species we consider a pest and introduce them to an area where the pests are a problem.

D. Biological control agents themselves can become pests.

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1. Scientists argue over the relative benefits and risks of biocontrol measures.

E. Integrated pest management combines biocontrol and chemical methods.

1. Integrated pest management (IPM) uses numerous techniques, including biocontrol, chemicals, population monitoring, habitat alteration, crop rotation, transgenic crops, alternative tillage methods, and mechanical pest removal.

F. We depend on insects to pollinate crops.

1. Pollination is the process by which male sex cells of a plant (pollen) fertilize female sex cells of the same species of plant; it is the botanical version of sexual intercourse.
2. While our staple grain crops are grasses that are wind-pollinated, many of our other crops depend on insects for pollination.
3. Populations of native pollinators have declined precipitously.

G. Conservation of pollinators is vital.

1. Preserving the biodiversity of native pollinators is especially important today because the domesticated workhorse of pollination, the honeybee *(Apis mellifera)*, is also declining.
2. Parasitic mites have been devastating the hives of these bees in recent years. In each of the last several years, up to one-third of all honeybees in the United States have vanished from what is being called *colony collapse disorder*.
3. Farmers and homeowners can help maintain populations of pollinators by reducing or eliminating pesticide use.

V. Genetically Modified Food

A. Genetic modification of organisms depends on recombinant DNA.

1. Genetic engineering is any process in which scientists directly manipulate an organism's genetic material in the lab by adding, deleting, or changing segments of DNA.
2. Genetically modified (GM) organisms have been genetically engineered using recombinant DNA technology, developed in the 1970s by scientists studying the *Escherichia coli* bacterium.
3. The creation of transgenic organisms is one type of biotechnology, which is the material application of biological science to create products derived from organisms.

B. Genetic engineering is like, and unlike, traditional breeding.

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1. The genetic alteration of plants and animals by humans is nothing new.
2. However, the new techniques mix genes of different species in the lab, involving experiments with genetic material apart from the organism, creating novel combinations never to be found in nature.

C. Biotechnology is transforming the products around us.

D. What are the benefits and impacts of GM crops?

1. Some fear the new foods might be dangerous. Others are concerned that transgenes might escape and pollute ecosystems and damage nontarget organisms. Still others worry that pests would evolve resistance to the supercrops and become "superpests," or that transgenes would be transferred from crops to other plants, ruining the integrity of native crops.
2. Supporters of GM crops maintain that transgenic crops are beneficial for the environment. Reasons include using less pesticide, no ill health effects to humans, and encouraging no-till farming.
3. Some say that we should adopt the precautionary principle and not undertake a new action until the ramifications of that action are well understood.
4. Studies thus far have shown no clear answers to questions about the impacts of GM crops.

E. Debate over GM foods involves more than science.

1. Ethical issues have played a large role in the debate over GM foods because the idea of "tinkering" with the food supply seems dangerous or morally wrong.
2. The perceived lack of control over one's own food has caused concern about a few large businesses dominating the global food supply.
3. So far, GM crops have not lived up to their promise of feeding the world's hungry.
   a. Most crops have been engineered to express pesticidal properties or herbicide tolerance—the herbicides are often manufactured and sold by the same companies.
   b. Crops with traits that might benefit poor farmers in developing countries have not been developed, perhaps because corporations have little economic incentive to do so.
4. Public relations has played a role.
   a. In Canada, Monsanto has been engaged in a high-publicity battle with a third-generation Saskatchewan farmer, Percy Schmeiser.

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b. European consumers have expressed widespread unease about possible risks of GM technologies.

c. Transnational spats between Europe and the United States will surely affect the future direction of agriculture.

d. Brazil, India, and China are now aggressively pursuing GM crops, even as ethical, economic, and political debates over the costs and benefits of these foods continue.

VI. Raising Animals for Food, Livestock, Poultry, and Aquaculture

A. Consumption of animal products is growing.

1. The world population of domesticated animals raised for food rose from 7.2 billion animals to 24.9 billion animals between 1961 and 2008. Most of these animals are chickens.

2. Global meat production has increased fivefold since 1950, and per-capita meat consumption has doubled.

B. Our food choices are also energy choices.

1. Eating meat is far less energy-efficient than relying on a vegetarian diet, and it leaves a far greater ecological footprint.

2. Producing eggs and chicken requires the least space and water, whereas producing beef requires the most.

3. Such differences make clear that when we choose what to eat, we are also indirectly choosing how to make use of resources such as land and water.

C. High consumption has led to feedlot agriculture.

1. **Feedlots**, or factory farms, are operations in which animals are housed in huge warehouses or pens where energy-rich food is provided to the animals who are living in extremely high densities.

2. Animals that are densely concentrated in feedlots will not contribute to overgrazing and soil degradation.

3. Waste from feedlots can emit strong odors, and can pollute surface water and groundwater.

4. Feedlot impact can be minimized when properly managed.

D. Livestock agriculture pollutes water and air.

1. Localized concentrations of pollution is the most noticeable environmental impact of feedlots.

2. Livestock produce prodigious amounts of manure and urine, and their waste can pollute surface water and groundwater.

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3. Moreover, the crowded and dirty conditions under which animals are often kept necessitate heavy use of antibiotics to control disease.
4. Feedlot impacts can be minimized when properly managed, and both the EPA and the states regulate U.S. feedlots.
5. Raising animals for food also results in air pollution.

E. We also raise fish on "farms."

1. Raising fish and shellfish on "fish farms" in controlled environments is aquaculture; it may be the only way to meet the demand for these foods because most fisheries are overharvested.

F. Aquaculture brings benefits.

1. Aquaculture provides a reliable source of protein for developing countries.
2. On a small scale, aquaculture is sustainable and is compatible with other activities.
3. On a large scale, aquaculture helps improve a nation's food security.
4. Aquaculture reduces fishing pressures on wild stocks.
5. Aquaculture relies far less on fossil fuels than do fishing vessels, and is very energy-efficient.
6. Aquaculture provides a safer work environment than does commercial fishing.

G. Aquaculture has negative impacts.

1. The dense concentrations of farmed animals can increase the incidence of disease and necessitates the use of antibiotics.
2. Aquaculture can also produce large amounts of waste, both from the organisms being farmed and from uneaten feed.
3. The escape of farmed animals into the environment can have negative consequences such as spreading disease, outcompeting native species, and introducing new genetic material to a native population.

VII. Sustainable Agriculture

A. We are moving toward sustainable agriculture.

1. Sustainable agriculture is farming that does not deplete soils faster than they form and does not reduce the amount of healthy soil, clean water, and genetic diversity essential to long-term crop and livestock production.

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2. *Low-input agriculture* is farming that uses smaller amounts of pesticides, fertilizers, growth hormones, water, and fossil fuel energy than is used in industrial agriculture.
3. Food growth practices that do not use synthetic fertilizers or pesticides are often termed organic agriculture.

B. Organic approaches reduce inputs and pollution.
1. In 1990, the U.S. Congress passed the Organic Food Production Act, which established national standards for organic products and facilitated the sale of organic food.
2. For farmers, organic farming can bring the benefits of lower input costs, enhanced income from higher-value produce, and reduced chemical pollution and soil degradation.
3. Farmers face obstacles to adopting organic methods. There are the risks and costs of shifting to new methods, particularly during the transition period, as U.S. farmers need to meet standards for three years before they can be certified.
4. Many consumers favor organic food out of concern that the pesticides, hormones, and antibiotics used in conventional agriculture pose health risks.
5. The main obstacle to adopting organic food for consumers is price.

C. Organic agriculture is booming.
1. Government initiatives have spurred the growth of organic farming.

D. Locally supported agriculture is growing.
1. The average food product sold in U.S. supermarkets travels at least 1,400 miles between the farm and the shelf, and is often chemically treated to preserve freshness and color.
2. At **farmers' markets**, consumers buy meat, fresh fruit, and vegetables in season from local producers.
3. Some consumers are even partnering with local farmers in a phenomenon called community-supported agriculture (CSA). In a CSA program, consumers pay farmers in advance for a share of their yield, usually a weekly delivery of produce.

E. Sustainable agriculture mimics natural ecosystems.
1. Treating agricultural systems as ecosystems is a key aspect of sustainable agriculture, and this general lesson applies regardless of location, scale, or the crop involved.

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VIII. Conclusion

A. Many of the intensive agricultural practices discussed have substantial negative environmental impacts, but have positive impacts as well.

B. If we are to support 9 billion people, we must make a shift to more sustainable agriculture.

Key Terms

aquaculture
bacillus thuringiensis (Bt)
biofuels
biological control (biocontrol)
biotechnology
Borlaug, Norman
community supported agriculture (CSA)
ethanol
farmers' markets
feedlots
food security
genetic engineering
genetically modified (GM) organisms
Green Revolution
integrated pest management (IPM)
landraces
malnutrition
monocultures
organic agriculture
overnutrition
pesticides
pollination
precautionary principle
recombinant DNA
seed banks
sustainable agriculture
transgenes
transgenic
undernutrition

Teaching Tips

1. Show the video segment "The Desert's Perfect Foods" from the *Scientific American Frontier* online video archive: (www.pbs.org/saf/1110/video/watchonline.htm)

This program illustrates how the occurrence of obesity and diabetes in the Pima and O'odham Indians of Arizona has greatly increased since they adopted a contemporary Western diet. It also shows the people's attempts to go back to their traditional diet of desert foods. The Tohono O'odham Community Action Pages (www.tocaonline.org/homepage.html) has links to information about native foods and diabetes, as does the Native Seeds/SEARCH website (www.nativeseeds.org). Ask students to research and describe some of the traditional foods that the Pima and O'odham Indians collect, prepare, and eat from their environment.

2. This chapter describes the use of pesticides in agriculture. By their nature, pesticides may pose harm to humans, pets, and the environment because they are designed to adversely affect and/or kill certain organisms.

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What some people do not realize is that many household products act as pesticides. It is extremely important to read the label of those products for their safe use and disposal. The Consumer Labeling Initiative (CLI) and its "Read the Label First" program (www.epa.gov/opptintr/labeling/campaign.htm) is an effort by the EPA to "foster pollution prevention, empower consumer choice, and improve consumer understanding of safe use, environmental, and health information on household consumer product labels."

To introduce students to pesticide labels, bring some pesticide products from home such as bug sprays, flea collars, and disinfectants. Have students bring in such products from their homes, too. Ask students to identify the warnings on the labels that the EPA requires.

3. Many people are concerned with the levels of pesticides and other agricultural chemicals in foods. The Food and Drug Administration conducts a Total Diet Study (also called the Market Basket Study) in several locations across the country. Its purpose is to determine the levels of various contaminants and nutrients in foods. Sample collections are carried out four times a year in each of four geographic regions of the country. FDA personnel buy about 280 foods from supermarkets, grocery stores, and fast-food restaurants in three cities in the region. The regional samples are shipped to a central FDA laboratory, prepared table-ready, combined to form a single analytical composite for each TDS food, and analyzed for pesticide residues, industrial chemicals, radionuclides, toxic and nutrient elements, and folate.

Students can determine the levels of contaminants in the foods they eat by going to the FDA pesticides website at www.cfsan.fda.gov/~lrd/pestadd.html

About two-thirds of the way down the page are links to the Total Diet Study, which analyzes the amount of pesticides in the average diet, based on age and sex. Download the TDS diet and import the data files into database software such as Excel, which will allow you to sort it, perform searches, or prepare reports as desired.

4. In October 2002, the USDA National Organic Program (www.ams.usda.gov/nop/indexIE.htm) published labeling standards for organic food that are based on the percentage of organic ingredients in a product:

- Products labeled "100 percent organic" must contain only organically produced ingredients and may display the USDA Organic Seal.
- Products labeled "organic" must consist of at least 95% organically produced ingredients and may display the USDA Organic Seal.
- Processed products that contain at least 70% organic ingredients can use the phrase "made with organic ingredients" and list up to three of the organic ingredients or food groups on the principal display panel. The USDA seal cannot be used anywhere on the package.

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- Processed products that contain less than 70% organic ingredients cannot use the term "organic" other than to identify in the ingredient statement the ingredients that are organically produced.

To investigate products, labels, and organic information, go to the Consumers Union eco-label website (www.eco-labels.org/home.cfm). Have students conduct a study on the common household products that they use. From the eco-label website, also have them click on the link "Visit our Virtual Kitchen" to see where eco-labels might be found in the home, as well as to access warnings about misleading labels. For example, click on the refrigerator, then click on the bag of ice to read comments about "natural ice."

5. Reading, interpreting, and creating graphs and charts are difficult tasks for many students. Consider having an introductory activity that explains the difference between continuous and discrete data, and the most useful graphing methods for each. *Continuous data* consist of a large number of values with no category label for the values. Are there more values possible between the listed values? If so, your data are probably continuous. In a study of tree health in a forest, there are many continuous variables, such as the height of each tree, the age of the tree as determined by coring, the number of main branches, etc.

Continuous data are usually best shown on a line graph because it can show that it is possible to understand information between the data points along the line.

Discrete or *categorical data* consist of only a small number of values, each corresponding to a specific category value or label. Tell students to ask themselves whether they can state all the possible categories or values of the data quickly. If they can, the data are probably discrete. In a study of tree health in a forest, there are many discrete variables, such as tree species, whether the tree is alive, whether there is significant insect damage, etc.

Discrete data are usually best shown with a bar graph, because it can show that these are distinct categories. For example, there can be pine and oak trees, but you can't have a tree that's a pine-oak. A line graph makes no sense for this type of data.

If you are illustrating the parts of a whole (for example, percentages of people choosing from a range of alternatives such as preferred automobile types and related mpg figures), then use a pie chart, indicating the proportion of the whole that each group uses.

6. Have students keep a log of what they ate in a 24-hour period, noting the country of origin for each food. Using a world map large enough for all students in the classroom to view, plot what local food security advocates call the "food miles" for the foods that the students ate. Consider a nominal reward for the person who had the meal that was most "local" in terms of what foods the region provides. (While not a food group, caffeine from coffee or tea counts in this activity.)

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Additional Resources

Websites

1. *Agriculture 21 Magazine,* Food and Agricultural Organization of the United Nations (www.fao.org/ag)

   This e-magazine has articles about agricultural topics from around the world such as biotechnology, new animal diseases, and conservation agriculture.

2. *National Agricultural Library,* Agricultural Research Service, United States Department of Agriculture (www.nal.usda.gov)

   This online library is a major international source for agriculture and related information.

3. *Animal Feeding Operations,* National Pollution Discharge Elimination System, U.S. Environmental Protection Agency (http://cfpub.epa.gov/npdes/home.cfm?program_id=7)

   This website is an overview of animal feeding operations and the regulation of animal waste.

4. *Feeding the World Through Responsible Aquaculture*, Global Aquaculture Alliance (www.gaalliance.org)

   The Global Aquaculture Alliance is an international association dedicated to promoting best management practices for sustainable aquaculture.

5. Organic Consumers Association. (http://www.organicconsumers.org/gefood/safewayprotest051002.cfm)

   A consumer-driven website with information on topics ranging from organic/chemical-free clothing to contemporary issues dealing with pesticide residue on foods.

6. *About Pesticides,* United States Environmental Protection Agency (www.epa.gov/pesticides/about/index.htm)

   This EPA website introduces pesticides and how they are regulated.

Audiovisual Materials

1. *GMOs & the Changing Face of Agriculture Series,* video series distributed by The Video Project (www.videoproject.com)

   This series of videos focuses on the spread of genetically modified organisms (GMOs) in our global food supply. The four films investigate the environmental, economic, and health consequences of this trend.

2. *Sowing Seeds of Hunger,* 2002, produced by Television Trust for the Environment and distributed by Bullfrog Films (www.bullfrogfilms.com)

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This program examines how the AIDS epidemic in sub-Saharan Africa has crippled the agricultural community while forcing children to undertake the responsibilities of farming.

3. *My Father's Garden,* 1995, produced by Miranda Productions and distributed by Bullfrog Films (www.bullfrogfilms.com)

   This documentary examines the use and misuse of technology on American farms, both industrial and organic.

4. *Corporate Agriculture: Cultivating Trouble,* 2004, distributed by Films for the Humanities & Sciences (www.films.com)

   This program examines the growth of corporate factory agriculture, an industry that can have environmental, social, and cultural repercussions.

5. *Alternative Agriculture: Food for Life,* 2004, distributed by Films for the Humanities & Sciences (www.films.com)

   Examines ecological, organic, and ethical farming as a viable alternative to industrial agriculture, and how this type of farming offers a tremendous benefit to the environment while helping to preserve traditional rural life.

6. *NOW with Bill Moyers: Seeds of Conflict.* October 4, 2002. Distributed by PBS.

   This episode examines the debate over the introduction of genetically modified food items into the human diet, their impact on local and global ecology, and the cultural impact surrounding systems of indigenous knowledge.

Weighing the Issues: Facts to Consider

The Green Revolution and Population

Facts to consider: Whether or not the green revolution was successful depends on one's perspective. The green revolution increased the world's food supply and supplied food to many hungry people by using high-yield crop plants. Initially, improved yield also reduced, or in some cases prevented, deforestation and protected wild lands from agricultural use. However, increased food supplies also increased the carrying capacity of various regions, which allowed the human population to increase as well. The increased crop yields used to feed an exponentially growing human population required nonsustainable farming methods such as increased fossil fuel use, the diversion of water for irrigation, and the application of chemical fertilizers and pesticides. The world's population has continued to grow during the green revolution, but its growth rate has slowed. So, to some extent, the green revolution and demographic transition theory have worked together to reduce the likelihood of widespread starvation. Some countries have been working more actively than others to reduce population growth rates, and

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some countries have had economic, social, and educational developments that tend to reduce birth rates.

Feedlots and Animal Rights

Facts to consider: Answers will vary. One approach to these questions is to consider the effect of the rising demand for meat. Agribusiness is responding by raising animals in as efficient a way as possible to respond to demand and maximize profits. Feedlots can be ecologically beneficial by removing large herds of grazing animals from grasslands and preventing the consequences that come with overgrazing. In terms of environmental safety, however, feedlots are a disaster. They introduce large amounts of fecal matter and growth hormones into surface and ground waters. Rising dust from livestock pens also releases fecal matter and strong odors into the air. Finally, when resource use is considered, livestock consume what humans could be consuming if the huge demand for meat were absent. Some people choose to become a vegetarians for these reasons. Reducing meat demand would free up much of the land needed to feed the increasing human population, and would decrease the need for feedlots, with their negative environmental impacts.

Do You Want Your Food Labeled?

Facts to consider: This question requires a personal response. All agriculture, and hence food choices, have good and bad environmental impacts. In the case of shade-grown coffee plantations, for example, how the coffee is grown has a positive effect on the ecosystem's flora and fauna. Eating produce and meat grown without chemical fertilizers, pesticides, and growth hormones keeps these persistent chemicals out of flora and fauna. These farming methods are expensive, and farmers—many of whom just barely break even financially during the year—revert to tried-and-true farming methods that are not environmentally friendly. Purchasing power has been an effective way for groups to make their views known about food preferences, some of which have, in fact, influenced food manufacturers. GM foods may be another area in which this proves to be the case.

The Science behind the Stories: Thinking Like a Scientist

Transgenic Contamination of Native Maize?

This vignette highlights that part of scientific inquiry not seen by the public: the debate and arguments within the scientific community caused by controversial research.

Original research: Researchers David Quist and Ignacio Chapela published a paper in the journal *Nature* concluding that a transgene found in genetically

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modified corn had found its way into the genome of native maize and changed locations within the genome after it had entered the native maize's DNA.

Critiques: Critics claimed that the i-PCR technique was an unreliable method, and that Quist and Chapela used insufficient controls. Matthew Metz of the University of Washington and Johannes Fütterer of the Institute of Plant Science in Zurich, Switzerland, both argued that the i-PCR results showed, at the most, first-generation hybrids between transgenic and native maize. Paul Christou, editor of the journal *Transgenic Research,* and others expressed concern that Quist and Chapela may not have been careful in their laboratory technique. Letters published in *Nature* stated that there was insufficient evidence to publish the paper.

Response: Quist and Chapela acknowledged that some of their initial findings, including the i-PCR results, were probably invalid. At the same time, they presented a new analysis to support their conclusions and referred to a study by the Mexican government that also found high rates of transgenic contamination.

Critique: The results of the Mexican government study were unpublished and had not been reviewed by peers.

Current situation: The debate became heated and personal both within and outside of academic circles. Opponents and supporters of GM crops leveled many personal attacks on each other as well as upon Quist and Chapela. After speaking out against a proposed partnership between his university and a biotechnology firm, Chapela was denied tenure, which was later awarded after a three-year fight. Researchers remained divided about this enthusiastically debated issue, where the lack of scientific data, combined with the high economic and environmental stakes surrounding Mexico's ban on transgenic corn, added fuel to the dispute.

Does Organic Farming Work?

Observation: In a 20-year study conducted by the Research Institute of Organic Agriculture in Switzerland, organically farmed crops were compared to conventionally farmed crops. Results showed that while the organically farmed fields received 35–50% less chemical fertilizer and 97% less pesticide, crop yields were 80% of those produced by conventional farming methods.

Hypothesis: Organic farms are better able to sustain high soil quality that produces substantial amounts of food.

Study: Following a study done in the United States in the mid-1990s that compared organic and conventional farms in North Dakota and Nebraska, the Swiss researchers conducted a 20-year comparative study that collected soil samples and analyzed soil quality.

Results: The U.S. researchers collected soil samples and analyzed the soil of their study farms for soil quality indicators such as water-holding ability, microbial biomass, and the amount of nutrients such as carbon and nitrogen. The U.S. study found that organic soils had more naturally occurring nutrients, held more water, had higher microbial biomass and diversity, and had a deeper topsoil layer and

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more earthworm activity -- all signs of healthy, fertile soil. The Swiss researchers analyzed similar soil quality indicators and saw results like those of the U.S. researchers in their organic plots. These results are helping researchers realize that organic farming and soil management support healthier soil with greater microbe diversity, resulting in self-sustaining fields and higher crop yields.

Answers to End-of-Chapter Questions

Testing Your Comprehension

1. Food production has been increased by cultivating more acres, by fertilizing and irrigating crops to alleviate nutrient limitations, by breeding more productive crops, and by increasing inputs of pesticides and fossil-fuel-derived power. Borlaug introduced high-yield, sturdy, disease-resistant wheat varieties to developing nations.
2. Pesticide resistance arises by natural selection. Following pesticide application, resistant individuals survive and reproduce at higher rates, and so greater resistance builds over the generations.
3. Biocontrol is the practice of using one species to limit the population size of another. For example, parasitoid wasps lay eggs on leaf-eating caterpillars, and the wasp larvae eventually kill the caterpillar. Integrated pest management (IPM) combines biocontrol and chemical methods to control pests. It uses close monitoring of populations, habitat alteration, crop rotation, transgenic crops, alternative tillage methods, and mechanical pest removal.
4. Over 800 species of cultivated plants rely on insects for pollination, including species from almonds to yams. In many cases, different species of insects are required to pollinate different species of plants, and so it is important to maintain all of those insect species.
5. Recombinant DNA has been patched together from the DNA of multiple organisms. A transgenic organism is formed when a section of DNA from one species is successfully integrated into the DNA of another. Genetic engineering is different from traditional breeding in two primary ways: It may mix together the genomes of different species, and it produces new genetic combinations that have not been through the process of natural selection in the context of whole organisms living in the field. Genetic engineering is similar to traditional breeding. It attempts to intentionally manipulate and change the genetic content of organisms in order to produce organisms with beneficial traits.
6. Genetically modified organisms (GMOs) are supported by some because of their potential to solve specific problems. They may reduce pesticide applications by engineering pesticide production into the crop, or they might increase the nutrient value of a crop, such as rice, by engineering in increased vitamin production.

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7. Scientific concerns related to GMOs include the potential for the transgenes to escape and produce "superpests" or "superweeds." Concern about the domination of the food supply by a few large businesses and, therefore, a loss of democratic control and personal autonomy, is why there is opposition to GM foods in Europe and the developing world.
8. One environmental benefit of feedlot operations is that they reduce the spatial extent of the animal herd's environmental impact. Locally, however, they produce a concentrated stream of waste that can pollute both water and air. Beef requires a larger input of feed per pound of edible produce than pork, chicken, or other animal products.
9. Aquaculture can help ensure a reliable protein source in the diet, and provides by-products to be used as crop fertilizer, thereby reducing the need for purchased inputs. Aquaculture does, however, increase the risk of disease in the confined population, and decrease the energy efficiency of food production, if the aquaculture is supported with grain feed.
10. Sustainable agriculture aims to produce food without diminishing the productive capacity of the land for future generations. Organic agriculture is on the rise because there is increasing demand for organic produce. Much of this demand stems from a desire to eat a healthier diet, and to improve environmental quality by reducing chemical pollution.

Calculating Ecological Footprints

Consumer	**Daily Cost**	**Annual Cost**
You	$1.40	$511
Your class	*Answers will vary*	*Answers will vary*
Your hometown	*Answers will vary*	*Answers will vary*
Your state	*Answers will vary*	*Answers will vary*
United States	$420,000,000	$153,300,000,000

1. The combustion of fossil fuels pollutes the atmosphere, generates waste heat that increases urban heat island effects, requires road construction and maintenance, vehicle production, and so on. Much of this system is fossil-fuel-dependent, and the long-term prognosis is that no such system can be sustained unless fossil fuels can be replaced.
2. The primary disadvantages to the consumer are that food variety and availability will be more variable, both from place to place and seasonally. Answers to the second part of the question will vary.
3. Answers will vary. Rising gasoline prices increase the transportation costs of bringing nonlocal food production to market, but do not change the environmental impact of doing so.

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