Food, Soil, and Pest Management

Chapter 12
Core Case Study: Grains of Hope or an Illusion?

- Vitamin A deficiency in some developing countries leads to
  - Blindness
  - Death

- 1999: Porrykus and Beyer
  - Genetically engineered rice with beta-carotene and more iron

- Is this the answer for malnutrition in these countries?

- Challenge of increased food production
12-1 What Is Food Security and Why Is It Difficult to Attain?

- **Concept 12-1A** Many of the poor suffer health problems from chronic lack of food and poor nutrition, while many people in developed countries have health problems from eating too much food.

- **Concept 12-1B** The greatest obstacles to providing enough food for everyone are poverty, political upheaval, corruption, war, and the harmful environmental effects of food production.
Many of the Poor Have Health Problems Because They Do Not Get Enough to Eat

- Food security

- Food insecurity
  - Root cause: poverty
Many People Suffer from Chronic Hunger and Malnutrition (1)

- **Macronutrients**
  - Carbohydrates
  - Proteins
  - Fats

- **Micronutrients**
  - Vitamins
  - Minerals
Many People Suffer from Chronic Hunger and Malnutrition (2)

- Chronic undernutrition, hunger
- Chronic malnutrition
- What progress in being made?
## Key Nutrients for a Healthy Human Life

### Table 12-1

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Food source</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proteins</td>
<td>Animals and some plants</td>
<td>Help to build and repair body tissues</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>Wheat, corn and rice</td>
<td>Provide short-term energy</td>
</tr>
<tr>
<td>Lipids (oils and fats)</td>
<td>Animal fats, nuts, oils</td>
<td>Help to build membrane tissues and create hormones</td>
</tr>
</tbody>
</table>
Many People Do No Get Enough Vitamins and Minerals

- Most often vitamin and mineral deficiencies in people in developing countries
  - Iron
  - Vitamin A
  - Iodine
  - Golden rice
Woman with Goiter in Bangladesh

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Acute Food Shortages Can Lead to Famines

- **Famine**
  - Usually caused by crop failures from
    - Drought
    - Flooding
    - War
    - Other catastrophic events
War and the Environment: Starving Children in Famine-Stricken Sudan, Africa
Many People Have Health Problems from Eating Too Much

- **Overnutrition**

- Similar health problems to those who are underfed
  - Lower life expectancy
  - Greater susceptibility to disease and illness
  - Lower productivity and life quality
12-2 How Is Food Produced?

- **Concept 12-2A**  We have sharply increased crop production using a mix of industrialized and traditional agriculture.

- **Concept 12-2B**  We have used industrialized and traditional methods to greatly increase supplies of meat, fish, and shellfish.
Food Production Has Increased Dramatically

- Three systems produce most of our food
  - Croplands: 77%
  - Rangelands, pastures, and feedlots: 16%
  - Aquaculture: 7%

- Importance of wheat, rice, and corn

- Tremendous increase in global food production
Industrialized agriculture, high-input agriculture
- Goal is to steadily increase crop yield
  - Plantation agriculture: cash crops
  - Increased use of greenhouses to raise crops
Satellite Images of Greenhouse Land Used in the Production of Food Crops
Traditional Agriculture Often Relies on Low-Input Polycultures

- Traditional subsistence agriculture
- Traditional intensive agriculture
- Polyculture
  - Benefits over monoculture
  - Slash-and-burn agriculture
Science Focus: Soil Is the Base of Life on Land

- Soil composition

- Soil formation

- Layers (horizons) of mature soils
  - O horizon: leaf litter
  - A horizon: topsoil
  - B horizon: subsoil
  - C horizon: parent material, often bedrock

- Soil erosion
Soil Formation and Generalized Soil Profile
A Closer Look at Industrialized Crop Production

- **Green Revolution**: increase crop yields
  - Monocultures of high-yield key crops
    - E.g., rice, wheat, and corn
  - Use large amounts of fertilizers, pesticides, and water
  - Multiple cropping

- **Second Green Revolution**

- World grain has tripled in production
Global Outlook: Total Worldwide Grain Production (Wheat, Corn, and Rice)
Total World Grain Production

- **Grain production** (millions of metric tons)
- **Year**

- 1960
- 1970
- 1980
- 1990
- 2000
- 2010

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Fig. 12-5a, p. 282
World Grain Production per Capita

Per capita grain production (kilograms per person)

Year

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Fig. 12-5b, p. 282
Per capita grain production (kilograms per person)

Year

World Grain Production per Capita

Fig. 12-5b, p. 282
Case Study: Industrialized Food Production in the United States

- Agribusiness
- Annual sales
- Food production: very efficient
- Percent of income spent on food
Crossbreeding and Genetic Engineering Can Produce New Crop Varieties (1)

- **Gene Revolution**
  - Cross-breeding through artificial selection
    - Slow process

- **Genetic engineering**
  - Genetic modified organisms (GMOs): transgenic organisms
Crossbreeding and Genetic Engineering Can Produce New Crop Varieties (2)

- **Age of Genetic Engineering**: developing crops that are resistant to
  - Heat and cold
  - Herbicides
  - Insect pests
  - Parasites
  - Viral diseases
  - Drought
  - Salty or acidic soil

- **Advanced tissue culture techniques**
Genetic Engineering: Steps in Genetically Modifying a Plant

Phase 1: Gene Transfer Preparations
- Extract DNA from plant cell
- Extract plasmid from plasmid DNA
- Foreign gene if interest

Phase 2: Make Transgenic Cell
- Agrobacterium takes up plasmid DNA
- Enzymes integrate plasmid into host cell DNA
- Foreign DNA
- Host DNA

Phase 3: Grow Genetically Engineered Plant
- Cell division of transgenic cells
- Cultured cells divide and grow into plants (otherwise tetraploid)
- Transgenic plants with desired trait

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Phase 1 Gene Transfer Preparations

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- Foreign gene integrated into plasmid DNA.

Phase 2 Make Transgenic Cell

- Agrobacterium takes up plasmid
- Enzymes integrate plasmid into host cell DNA.

Phase 3 Grow Genetically Engineered Plant

- Cell division of transgenic cells
- Cultured cells divide and grow into plantlets (otherwise teleological)
- Transgenic plants with desired trait

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Fig. 12-6, p. 283
Meat Production and Consumption Have Grown Steadily

- Animals for meat raised in
  - Pastures
  - Feedlots

- Meat production increased fourfold between 1961 and 2007

- Demand is expected to go higher
Industrialized Meat Production
Fish and Shellfish Production Have Increased Dramatically

- **Aquaculture, blue revolution**
  - World’s fastest-growing type of food production
  - Dominated by operations that raise herbivorous species

- **Polyaquaculture**
World Fish Catch, Including Both Wild Catch and Aquaculture
Fig. 12-8a, p. 285

The graph illustrates the total world fish catch from 1950 to 2010, comparing wild catch and aquaculture. The wild catch line shows a steady increase, while the aquaculture line shows a more rapid and continuous rise, particularly since the 1990s.
Fig. 12-8a, p. 285
Fig. 12-8b, p. 285

Per capita catch (kilograms per person)

Year

World Fish Catch per Person
Animation: Pesticide examples
Active Figure: Soil profile

- deciduous forest
- tropical rain forest
- coniferous forest
- grassland
- desert

- O horizon (scattered litter)
- A horizon (topsoil)
- B horizon
- C horizon (underlying rock)
Animation: Transferring genes into plants

1. Genetically engineer bacteria
2. Make transgenic cell
3. Grow transgenic plant

Pause Animation
Reset Animation

PLAY
Concept 12-3  Food production in the future may be limited by its serious environmental impacts, including soil erosion and degradation, desertification, water and air pollution, greenhouse gas emissions, and degradation and destruction of biodiversity.
Produce food has major environmental impacts.

- Harmful effects of agriculture on
- Biodiversity
- Soil
- Water
- Air
- Human health
Major Harmful Environmental Effects on Food Production

**NATURAL CAPITAL DEGRADATION**

**Food Production**

**Biodiversity Loss**
- Loss and degradation of grasslands, forests, and wetlands
- Fish kills from pesticide runoff
- Killing wild predators to protect livestock
- Loss of genetic diversity of wild crop strains replaced by monoculture strains

**Soil**
- Erosion
- Loss of fertility
- Salinization
- Waterlogging
- Desertification

**Water**
- Water waste
- Aquifer depletion
- Increased runoff, sediment pollution, and flooding from cleared land
- Pollution from pesticides and fertilizers
- Algal blooms and fish kills in lakes and rivers caused by runoff of fertilizers and agricultural wastes

**Air Pollution**
- Greenhouse gas emissions (CO₂) from fossil fuel use
- Greenhouse gas emissions (N₂O) from use of inorganic fertilizers
- Greenhouse gas emissions of methane (CH₄) by cattle (mostly belching)
- Other air pollutants from fossil fuel use and pesticide sprays

**Human Health**
- Nitrates in drinking water (blue baby)
- Pesticide residues in drinking water, food, and air
- Contamination of drinking and swimming water from livestock wastes
- Bacterial contamination of meat

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### NATURAL CAPITAL DEGRADATION

#### Food Production

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<th>Water</th>
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Topsoil Erosion Is a Serious Problem in Parts of the World

- Soil erosion
  - Natural causes
  - Human causes

- Two major harmful effects of soil erosion
  - Loss of soil fertility
  - Water pollution
Natural Capital Degradation: Severe Gully Erosion on Cropland in Bolivia
Natural Capital Degradation: Global Soil Erosion
Drought and Human Activities Are Degrading Drylands

- Desertification
  - Moderate
  - Severe
  - Very severe

- Effect of global warming on desertification
Severe Desertification
Natural Capital Degradation: Desertification of Arid and Semiarid Lands
Excessive Irrigation Has Serious Consequences

- Irrigation problems
  - Salinization
  - Waterlogging
Natural Capital Degradation: Severe Salinization on Heavily Irrigated Land
There May Be Limits to Expanding the Green Revolutions

- Can we expand the green revolution by
  - Irrigating more cropland?
  - Improving the efficiency of irrigation?
  - Cultivating more land? Marginal land?
  - Using GMOs?
  - Multicropping?
Industrialized Food Production Requires Huge Inputs of Energy

- Industrialized food production and consumption have a large net energy loss.
Industrialized Agriculture uses ~17% of All Commercial Energy Used in the U.S.
Crops

Livestock

Food processing

Food distribution and preparation
There Is Controversy over Genetically Engineered Foods

- Pros
- Cons
- What about chimeraplasty?
## Trade-Offs: Genetically Modified Crops and Foods

### Projected Advantages
- Need less fertilizer
- Need less water
- More resistant to insects, disease, frost, and drought
- Grow faster
- Can grow in slightly salty soils
- May need less pesticides
- Tolerate higher levels of herbicides
- Higher yields
- Less spoilage

### Projected Disadvantages
- Irreversible and unpredictable genetic and ecological effects
- Harmful toxins in food from possible plant cell mutations
- New allergens in food
- Lower nutrition
- Increase in pesticide-resistant insects, herbicide-resistant weeds, and plant diseases
- Can harm beneficial insects
- Lower genetic diversity

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### TRADE-OFFS

**Genetically Modified Crops and Foods**

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Food and Biofuel Production Systems Have Caused Major Biodiversity Losses

- Biodiversity threatened when
  - Forest and grasslands are replaced with croplands

- Agrobiodiversity threatened when
  - Human-engineered monocultures are used

- Importance of seed banks
  - Newest: underground vault in the Norwegian Arctic
Industrialized Meat Production Has Harmful Environmental Consequences

- Advantages
- Disadvantages
Trade-Offs: Animal Feedlots

**Advantages**
- Increased meat production
- Higher profits
- Less land use
- Reduced overgrazing
- Reduced soil erosion
- Protection of biodiversity

**Disadvantages**
- Large inputs of grain, fish meal, water, and fossil fuels
- Greenhouse gas (CO₂ and CH₄) emissions
- Concentration of animal wastes that can pollute water
- Use of antibiotics can increase genetic resistance to microbes in humans
TRADE-OFFS

Animal Feedlots

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Disadvantages

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- Greenhouse gas (CO$_2$ and CH$_4$) emissions
- Concentration of animal wastes that can pollute water
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Producing Fish through Aquaculture Can Harm Aquatic Ecosystems

- Advantages

- Disadvantages
Trade-Offs: Aquaculture

**Advantages**
- High efficiency
- High yield in small volume of water
- Can reduce overharvesting of fisheries
- Low fuel use
- High profits

**Disadvantages**
- Needs large inputs of land, feed, and water
- Large waste output
- Can destroy mangrove forests and estuaries
- Uses grain to feed some species
- Dense populations vulnerable to disease
TRADE-OFFS

**Aquaculture**

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Uses grain to feed some species
Animation: Land use

- 26% potentially usable
- 21% in use
- 51% not usable
Concept 12-4  We can sharply cut pesticide use without decreasing crop yields by using a mix of cultivation techniques, biological pest controls, and small amounts of selected chemical pesticides as a last resort (integrated pest management).
Nature Controls the Populations of Most Pests

- What is a pest?

- Natural enemies—predators, parasites, disease organisms—control pests
  - In natural ecosystems
  - In many polyculture agroecosystems

- What will happen if we kill the pests?
Natural Capital: Spiders are Important Insect Predators
We Use Pesticides to Try to Control Pest Populations (1)

- **Pesticides**
  - Insecticides
  - Herbicides
  - Fungicides
  - Rodenticides

- Herbivores overcome plant defenses through natural selection: coevolution
We Use Pesticides to Try to Control Pest Populations (2)

- First-generation pesticides
- Second-generation pesticides
  - Paul Muller: DDT
  - Benefits versus harm
- Broad-spectrum agents
- Persistence
Individuals Matter: Rachel Carson

- Biologist
- *Silent Spring*
- Potential threats of uncontrolled use of pesticides
Rachel Carson, Biologist
Modern Synthetic Pesticides Have Several Advantages

- Save human lives
- Increases food supplies and profits for farmers
- Work quickly
- Health risks are very low relative to their benefits
- New pest control methods: safer and more effective
Modern Synthetic Pesticides Have Several Disadvantages (1)

- Accelerate the development of genetic resistance to pesticides by pest organisms
- Expensive for farmers
- Some insecticides kill natural predators and parasites that help control the pest population
- Pollution in the environment
- Some harm wildlife
- Some are human health hazards
Modern Synthetic Pesticides Have Several Disadvantages (2)

- David Pimentel: Pesticide use has not reduced U.S. crop loss to pests
  - Loss of crops is about 31%, even with 33-fold increase in pesticide use
  - High environmental, health, and social costs with use
  - Use alternative pest management practices

- Pesticide industry refutes these findings
**Trade-Offs: Conventional Chemical Pesticides**

### Advantages
- Save lives
- Increase food supplies
- Profitable
- Work fast
- Safe if used properly

### Disadvantages
- Promote genetic resistance
- Kill natural pest enemies
- Pollute the environment
- Can harm wildlife and people
- Are expensive for farmers

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TRADE-OFFS

Conventional Chemical Pesticides

Advantages

- Save lives
- Increase food supplies
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Disadvantages

- Promote genetic resistance
- Kill natural pest enemies
- Pollute the environment
- Can harm wildlife and people
- Are expensive for farmers
Science Focus: Glyphosate-Resistant Crop Weed Management System: A Dilemma

- Best-selling herbicide (*Roundup*)
  
  - Advantages
  
  - Disadvantages
What Can You Do? Reducing Exposure to Pesticides

WHAT CAN YOU DO?

Reducing Exposure of Pesticides

- Grow some of your food using organic methods.
- Buy organic food.
- Wash and scrub all fresh fruits, vegetables, and wild foods you pick.
- Eat less or no meat.
- Trim the fat from meat.
Case Study: Ecological Surprises

- 1955: Dieldrin sprayed to control mosquitoes
- Malaria was controlled
- Dieldrin didn’t leave the food chain
- Domino effect of the spraying
- Happy ending
Laws and Treaties Can Help to Protect Us from the Harmful Effects of Pesticides

- U.S. federal agencies
  - EPA
  - USDA
  - FDA

- Effects of active and inactive pesticide ingredients are poorly documented

- Circle of poison, boomerang effect
There Are Alternatives to Using Pesticides (1)

- Fool the pest
- Provide homes for pest enemies
- Implant genetic resistance
- Bring in natural enemies
There Are Alternatives to Using Pesticides (2)

- Use insect perfumes
  - E.g., pheromones

- Bring in hormones

- Scald them with hot water
Solutions: An Example of Genetic Engineering to Reduce Pest Damage
Natural Capital: Biological Pest Control
Integrated Pest Management Is a Component of Sustainable Agriculture

- **Integrated pest management (IPM)**
  - Coordinate: cultivation, biological controls, and chemical tools to reduce crop damage to an economically tolerable level

- Disadvantages
Concept 12-5  We can improve food security by creating programs to reduce poverty and chronic malnutrition, relying more on locally grown food, and cutting food waste.
Use Government Policies to Improve Food Production and Security (1)

- Control prices
- Provide subsidies
- Let the marketplace decide
Use Government Policies to Improve Food Production and Security (2)

- United Nations Children’s Fund (UNICEF) suggests these measures
  - Immunizing children against childhood diseases
  - Encourage breast-feeding
  - Prevent dehydration in infants and children
  - Provide family planning services
  - Increase education for women
12-6 How Can We Produce Food More Sustainably? (1)

- **Concept 12-6A** Sustainable food production will require reducing topsoil erosion, eliminating overgrazing and overfishing, irrigating more efficiently, using integrated pest management, promoting agrobiodiversity, and providing government subsidies for more sustainable farming, fishing, and aquaculture.
Concept 12-6B  Producing enough food to feed the rapidly growing human population will require growing crops in a mix of monocultures and polycultures and decreasing the enormous environmental impacts of industrialized food production.
Reduce Soil Erosion

- Soil conservation, some methods
  - Terracing
  - Contour planting
  - Strip cropping with cover crop
  - Alley cropping, agroforestry
  - Windbreaks or shelterbeds
  - Conservation-tillage farming
    - No-till
    - Minimum tillage

- Identify erosion hotspots
(a) Terracing
(a) Terracing
(b) Contour planting and strip cropping
(b) Contour planting and strip cropping
(c) Alley cropping

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(c) Alley cropping
(d) Windbreaks

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(d) Windbreaks
(a) Terracing

(b) Contour planting and strip cropping

(c) Alley cropping

(d) Windbreaks

Fig. 12-24, p. 302
Solutions: Mixture of Monoculture Crops Planted in Strips on a Farm
Case Study: Soil Erosion in the United States—Learning from the Past

- What happened in the Dust Bowl in the 1930s?
- Migrations to the East, West, and Midwest
- 1935: Soil Erosion Act
- More soil conservation needed
Natural Capital Degradation: Dust Storm, Driven by Wind Blowing across Eroded Soil
Natural Capital Degradation: The Dust Bowl of the Great Plains, U.S.
Restore Soil Fertility

- Organic fertilizer
  - Animal manure
  - Green manure
  - Compost

- Commercial inorganic fertilizer active ingredients
  - Nitrogen
  - Phosphorous
  - Potassium
Reduce Soil Salinization and Desertification

- Soil salinization
  - Prevention
  - Clean-up

- Desertification, reduce
  - Population growth
  - Overgrazing
  - Deforestation
  - Destructive forms of planting, irrigation, and mining
Solutions: Soil Salinization

**Prevention**
- Reduce irrigation
- Switch to salt-tolerant crops (such as barley, cotton, and sugar beet)

**Cleanup**
- Flush soil (expensive and wastes water)
- Stop growing crops for 2–5 years
- Install underground drainage systems (expensive)
SOLUTIONS

Soil Salinization

**Prevention**

Reduce irrigation

Switch to salt-tolerant crops (such as barley, cotton, and sugar beet)

**Cleanup**

Flush soil (expensive and wastes water)

Stop growing crops for 2–5 years

Install underground drainage systems (expensive)
Practice More Sustainable Aquaculture

- Open-ocean aquaculture
  - Choose herbivorous fish

- Polyculture
Solutions: More Sustainable Aquaculture

- Restrict locations of fish farms to reduce losses of mangrove forests and estuaries
- Improve management of aquaculture wastes
- Reduce escape of aquaculture species into the wild
- Raise some aquaculture species in deeply submerged cages to protect them from wave action and predators and to allow dilution of wastes into the ocean
- Certify sustainable forms of aquaculture and label products accordingly

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Produce Meat More Efficiently and Humanely

- Shift to more grain-efficient forms of protein
- Shift to farmed herbivorous fish
- Develop meat substitutes; eat less meat
- Whole Food Markets: more humane treatment of animals
Efficiency of Converting Grain into Animal Protein

- Beef cattle: 7
- Pigs: 4
- Chicken: 2.2
- Fish (catfish or carp): 2

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Beef cattle: 7
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Shift to More Sustainable Agriculture (1)

- Paul Mader and David Dubois
  - 22-year study
  - Compared organic and conventional farming

- Benefits of organic farming
Shift to More Sustainable Agriculture (2)

- Strategies for more sustainable agriculture
  - Research on organic agriculture with human nutrition in mind
  - Show farmers how organic agricultural systems work
  - Subsidies and foreign aid
  - Training programs; college curricula
# Solutions: Sustainable Organic Agriculture

## More
- High-yield polyculture
- Organic fertilizers
- Biological pest control
- Integrated pest management
- Efficient irrigation
- Perennial crops
- Crop rotation
- Water-efficient crops
- Soil conservation
- Subsidies for sustainable farming and fishing

## Less
- Soil erosion
- Aquifer depletion
- Overgrazing
- Overfishing
- Loss of biodiversity
- Food waste
- Subsidies for unsustainable farming and fishing
- Soil salinization
- Population growth
- Poverty
SOLUTIONS

Sustainable Organic Agriculture

More
- High-yield polyculture
- Organic fertilizers
- Biological pest control
- Integrated pest management
- Efficient irrigation
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- Loss of biodiversity
- Food waste
- Subsidies for unsustainable farming and fishing
- Soil salinization
- Population growth
- Poverty

Fig. 12-31, p. 307
Solutions: Organic Farming

- Improves soil fertility
- Reduces soil erosion
- Retains more water in soil during drought years
- Uses about 30% less energy per unit of yield
- Lowers CO₂ emissions
- Reduces water pollution by recycling livestock wastes
- Eliminates pollution from pesticides
- Increases biodiversity above and below ground
- Benefits wildlife such as birds and bats
Organic Farming

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Reduces soil erosion
Retains more water in soil during drought years
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Increases biodiversity above and below ground
Benefits wildlife such as birds and bats
Science Focus: Scientists Are Studying Benefits and Costs of Organic Farming

- Effect of different fertilizers on nitrate leaching in apple trees
- Less nitrate leached into the soil after organic fertilizers were used
- Significance?
Science Focus: Sustainable Polycultures of Perennial Crops

- Polycultures of perennial crops
- Wes Jackson: natural systems agriculture benefits
  - No need to plow soil and replant each year
  - Reduces soil erosion and water pollution
  - Deeper roots – less irrigation needed
  - Less fertilizer and pesticides needed
Comparison of the Roots between an Annual Plant and a Perennial Plant
Buy Locally Grown Food

- Supports local economies
- Reduces environmental impact on food production
- Community-supported agriculture
What Can You Do? Sustainable Organic Agriculture

- Waste less food.
- Eat less or no meat.
- Use organic farming to grow some of your food.
- Buy organic food.
- Eat locally grown food.
- Compost food wastes.