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

Golden Rice: Genetically Engineered Strain of Rice Containing Beta-Carotene

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

Key Nutrients for a Healthy Human Life

Nutrient	Food source	Function
Proteins	Animals and some plants	Help to build and repair body tissues
Carbohydrates	Wheat, corn and rice	Provide short-term energy
Lipids (oils and fats)	Animal fats, nuts, oils	Help to build membrane tissues and create hormones

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

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 Crop Production Relies on High-Input Monocultures

- **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

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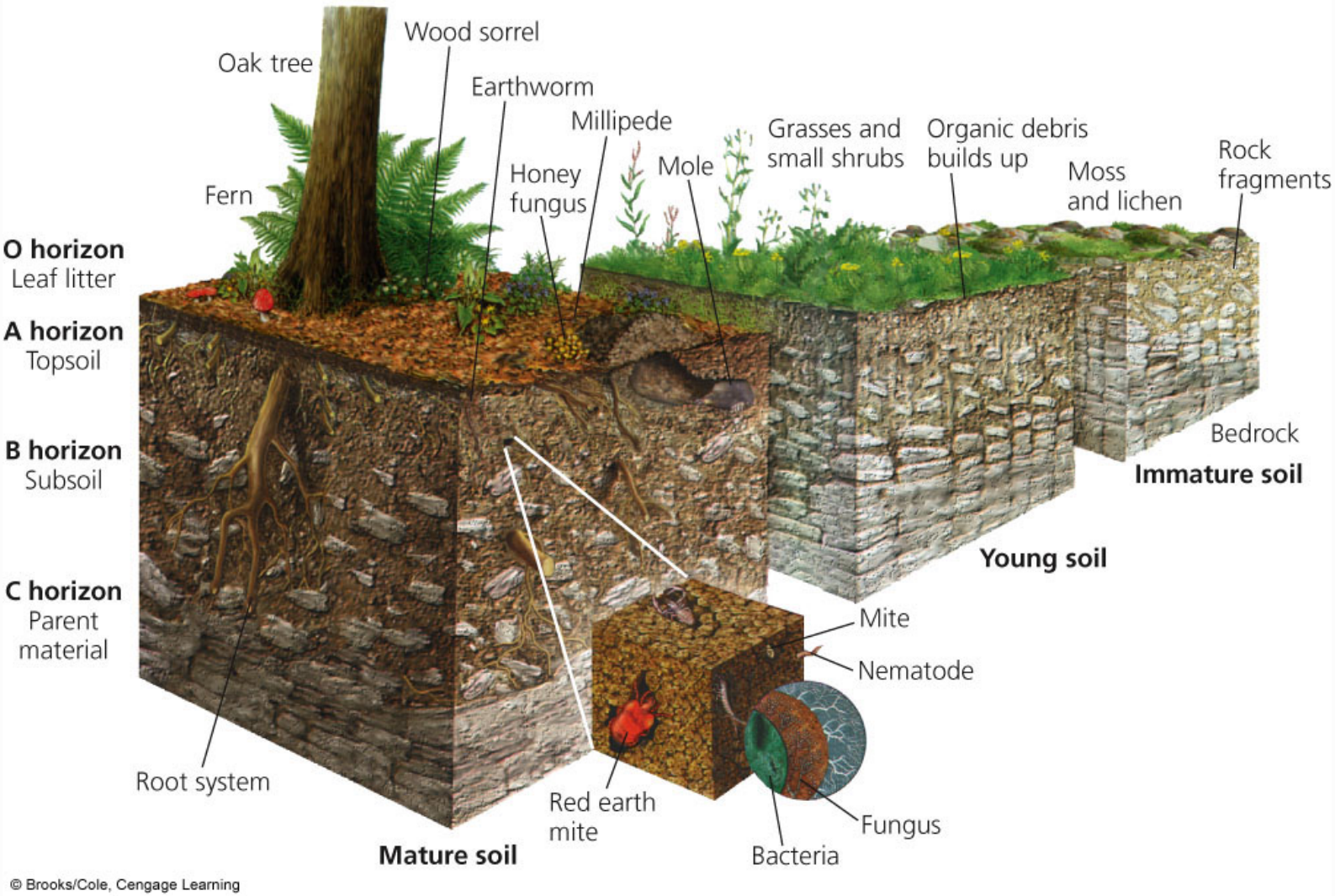
Traditional Agriculture Often Relies on Low-Input Polycultures

- **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



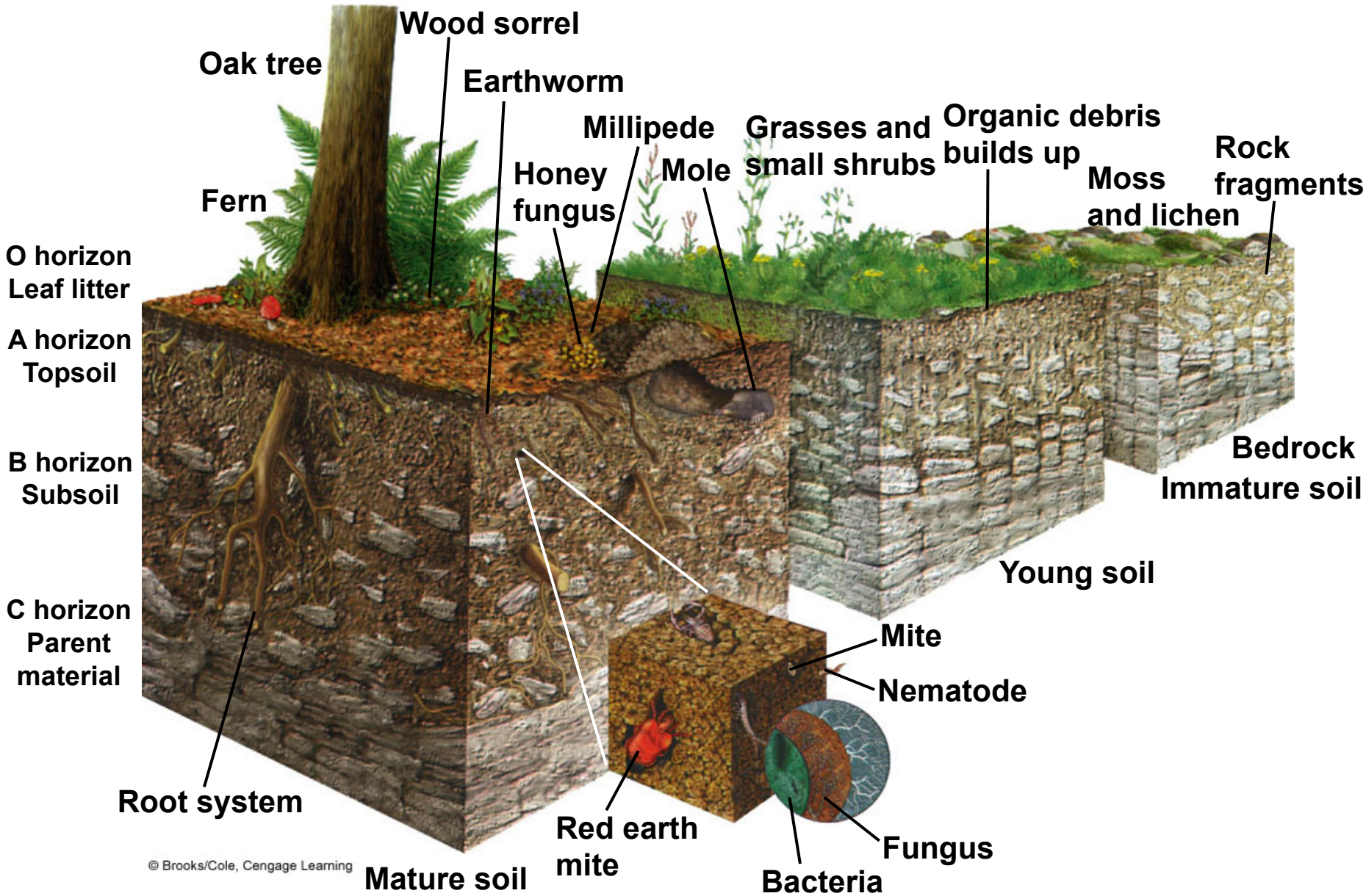

Wood sorrel
Oak tree
Earthworm
Millipede
Grasses and small shrubs
Organic debris builds up
Rock fragments
Honey fungus
Mole
Moss and lichen
Fern
O horizon
Leaf litter
A horizon
Topsoil
B horizon
Subsoil
C horizon
Parent material
Bedrock
Immature soil
Young soil
Mite
Nematode
Root system
Red earth mite
Fungus
Bacteria
Mature soil
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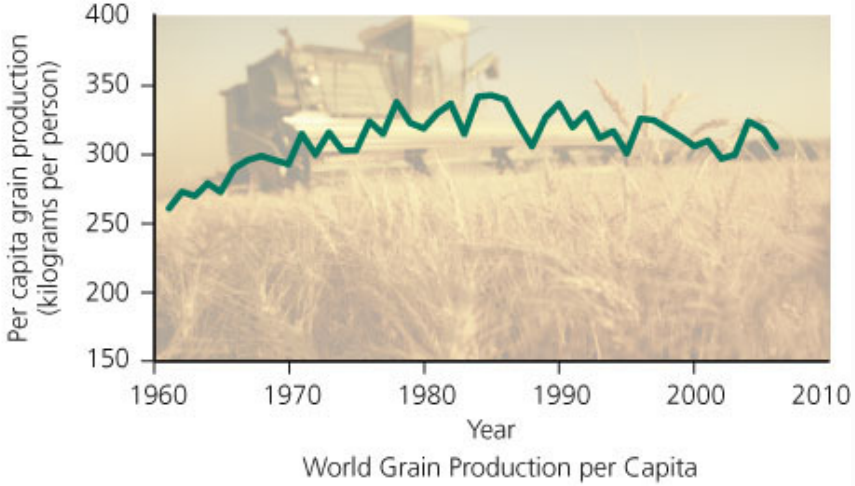
Fig. 12-A, p. 281

A Closer Look at Industrialized Crop Production

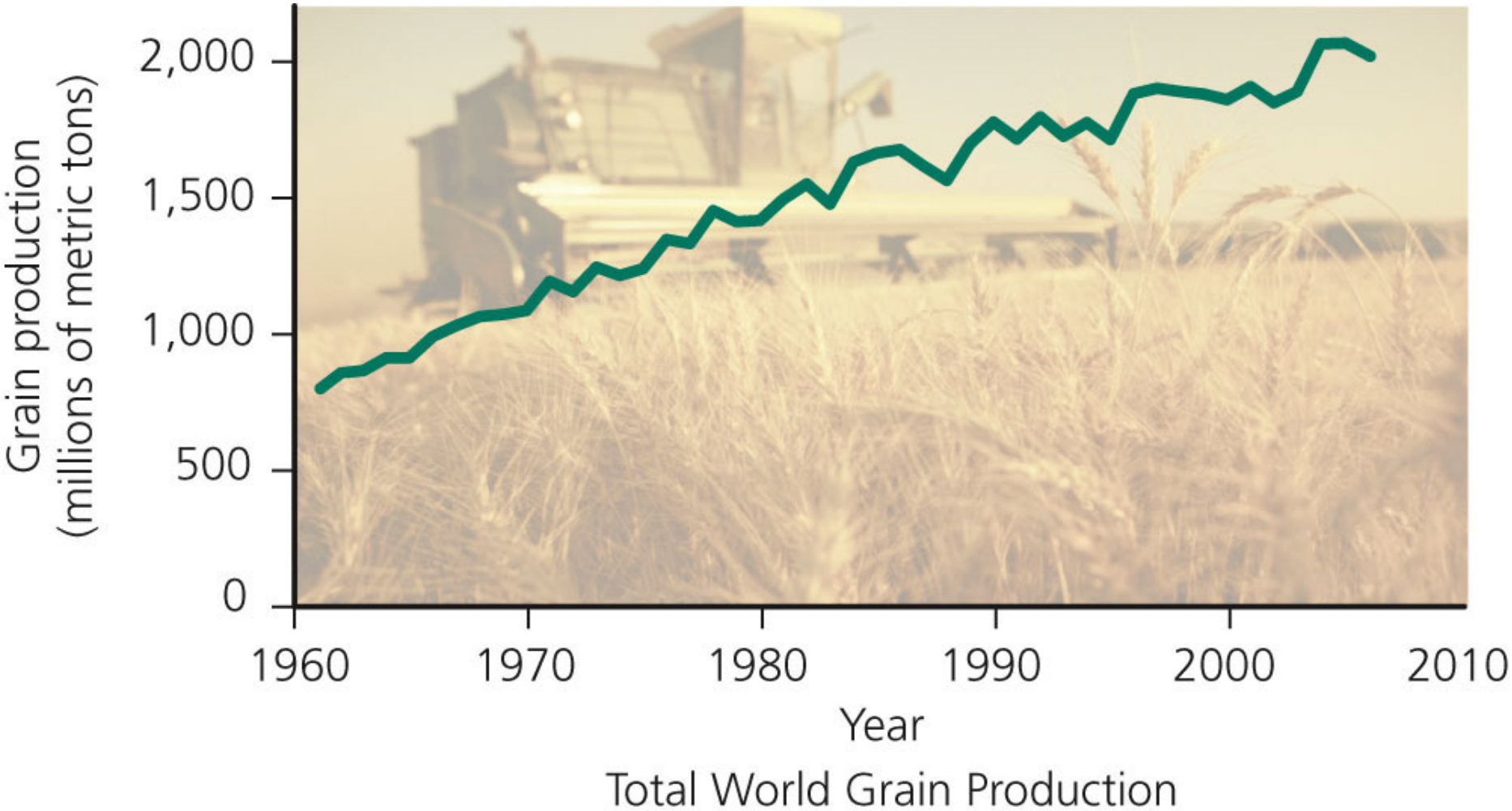
- **Green Revolution**: increase crop yields
  - Monocultures of high-yield key crops
    - E.g., rice, wheat, and corn
  - Use large amounts of fertilizers, pesticides, and water
  - **Multiple cropping**
- **Second Green Revolution**
- World grain has tripled in production

Global Outlook: Total Worldwide Grain Production (Wheat, Corn, and Rice)

Total World Grain Production

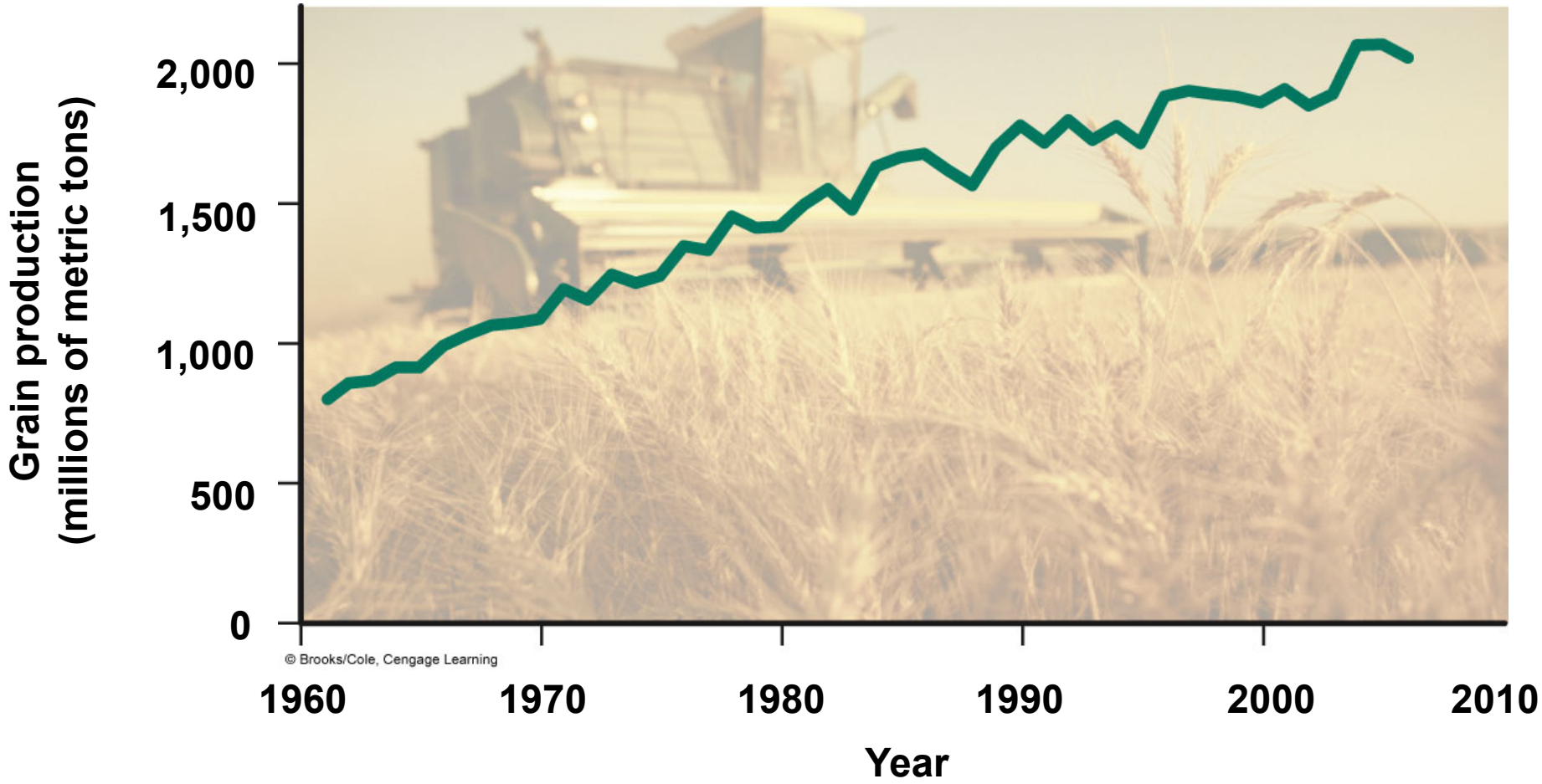


World Grain Production per Capita



Total World Grain Production

Fig. 12-5a, p. 282



Total World Grain Production

Fig. 12-5a, p. 282

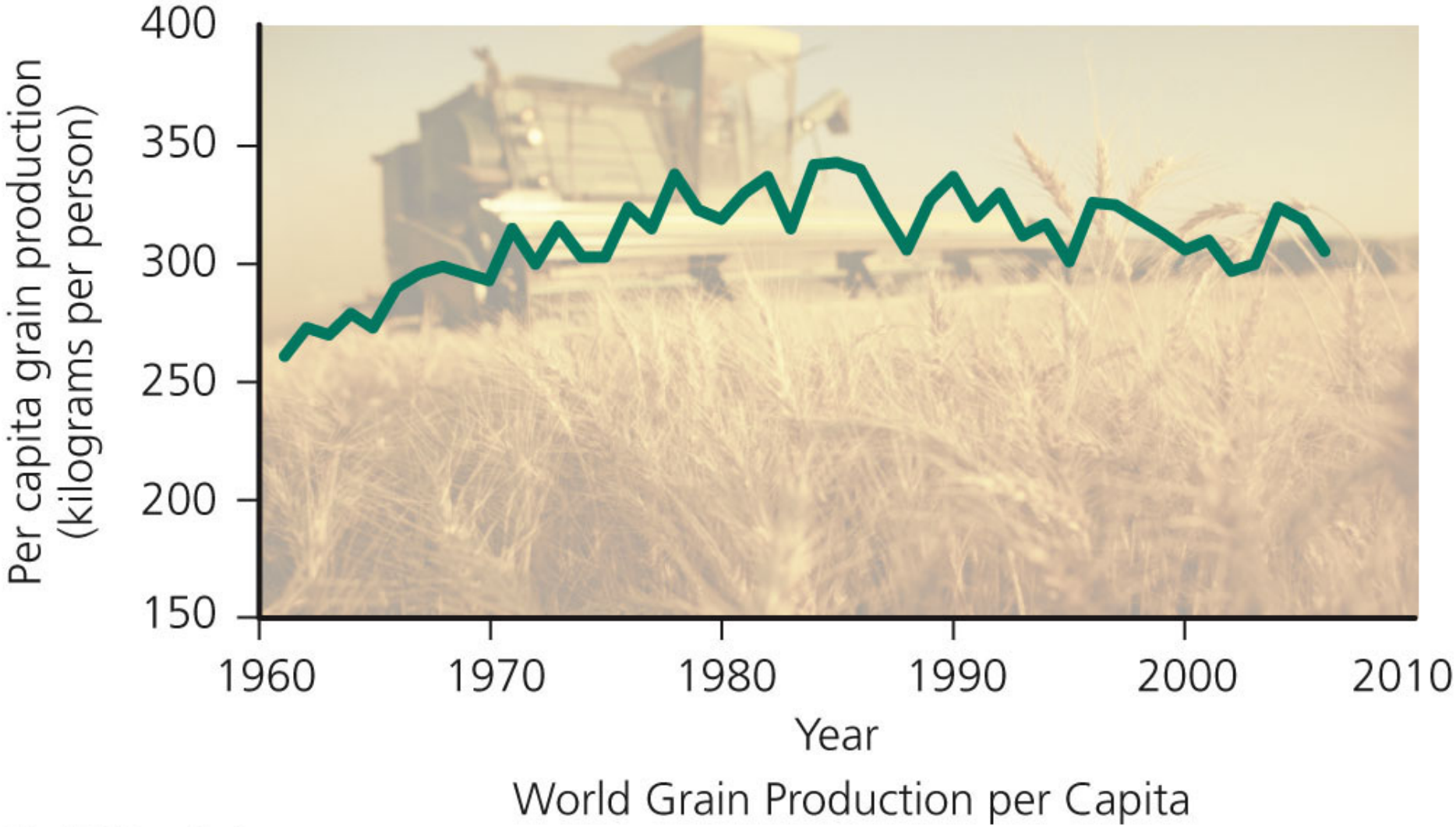
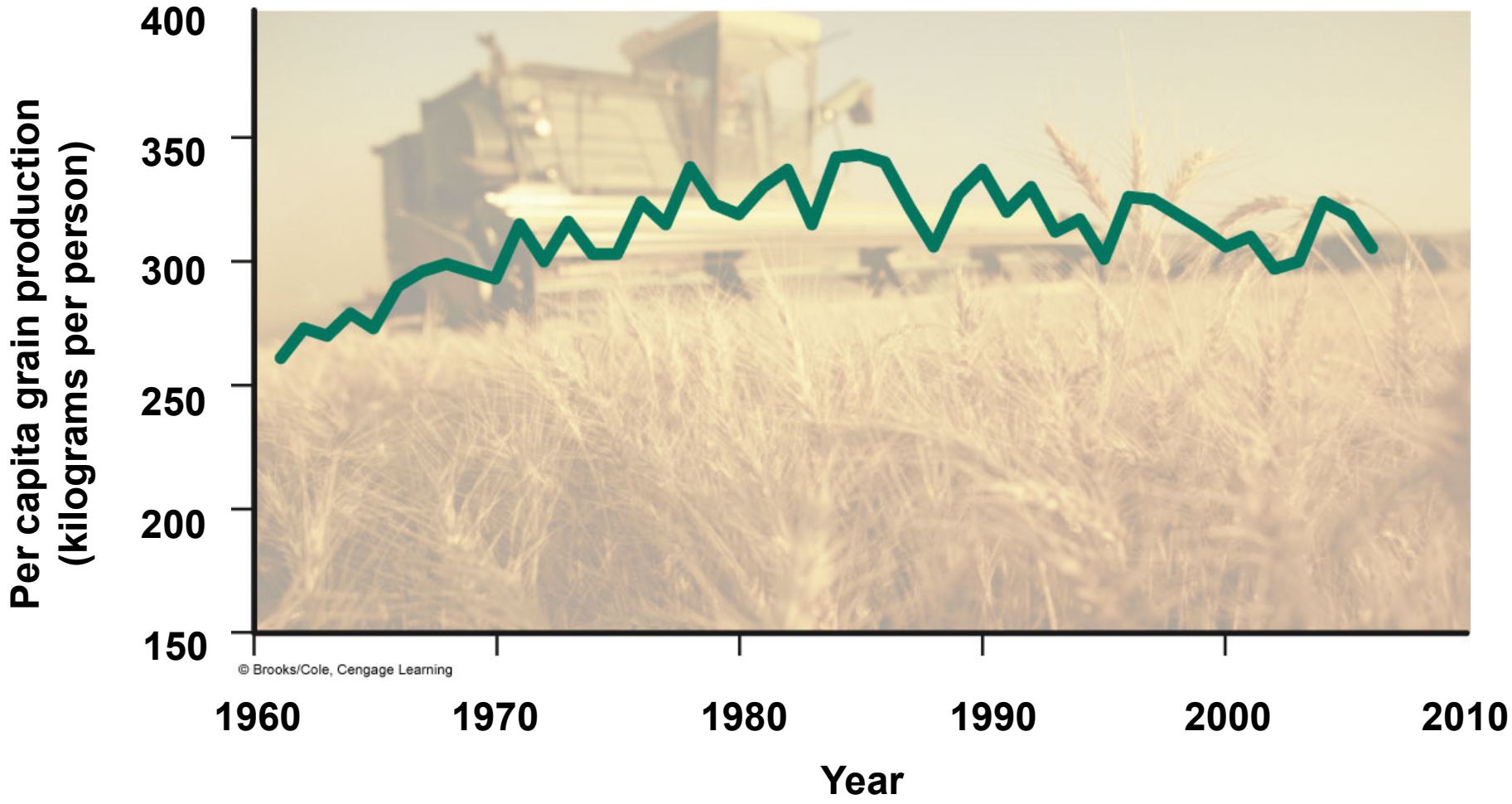


Fig. 12-5b, p. 282



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)

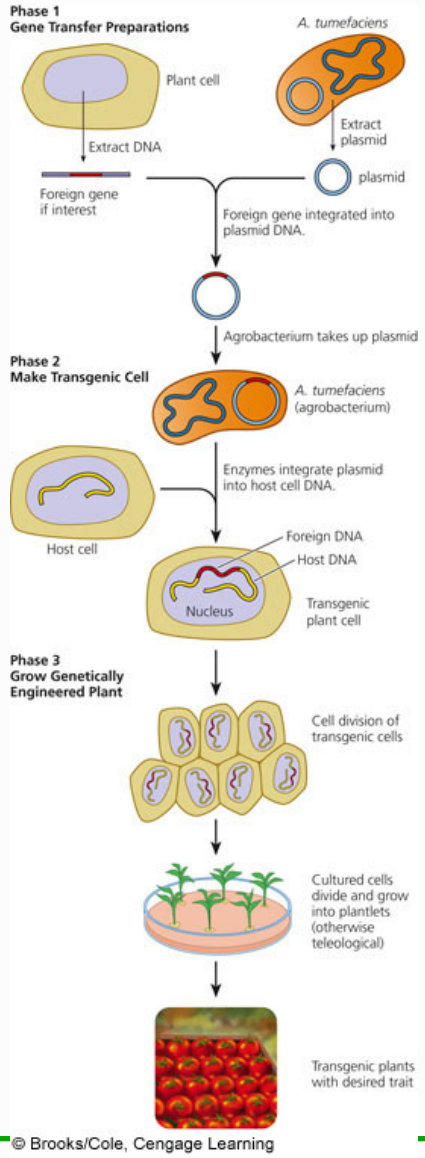
- **Gene Revolution**
  - **Cross-breeding** through **artificial selection**
    - Slow process
- **Genetic engineering**
  - **Genetic modified organisms (GMOs): transgenic organisms**

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



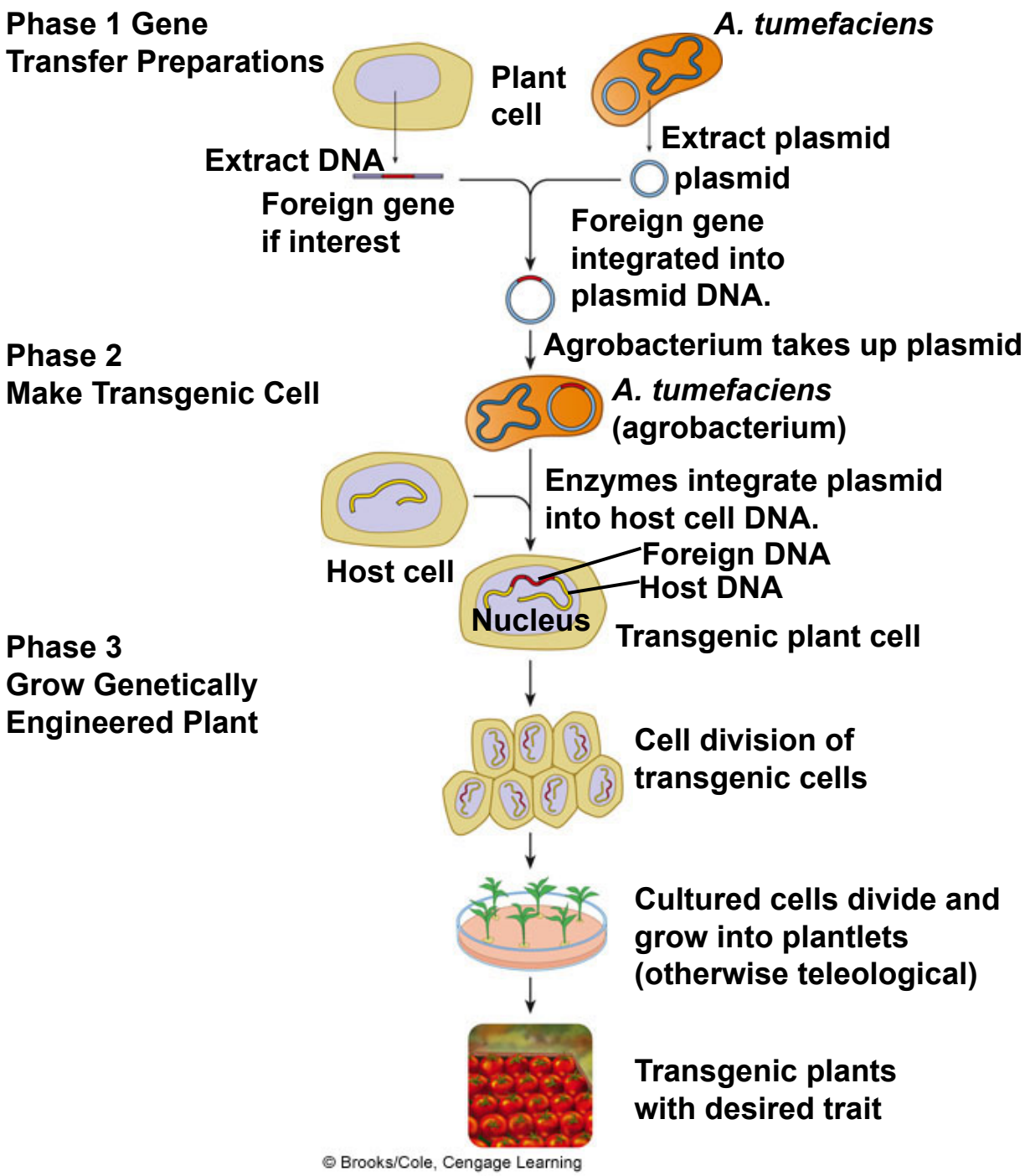


Fig. 12-6, p. 283

Meat Production and Consumption Have Grown Steadily

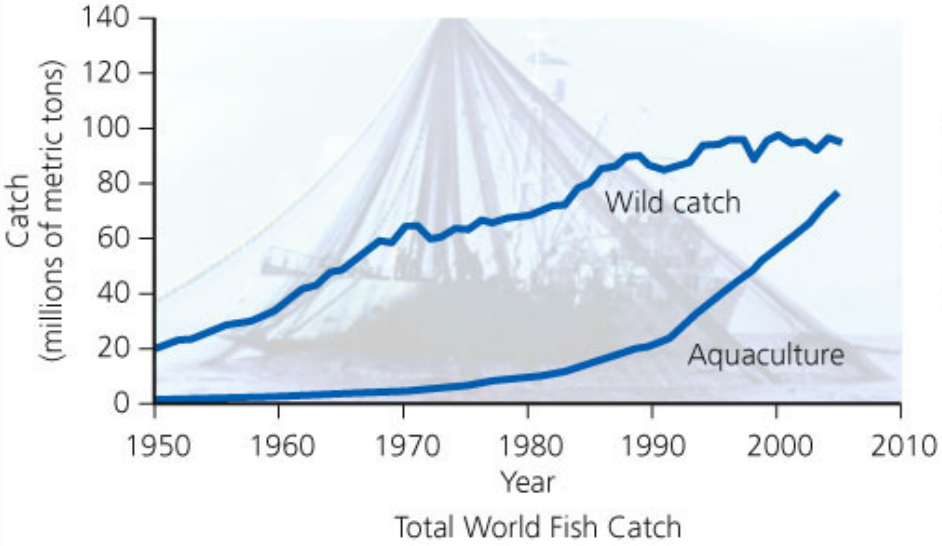
- Animals for meat raised in
  - Pastures
  - Feedlots
- Meat production increased fourfold between 1961 and 2007
- Demand is expected to go higher

Industrialized Meat Production

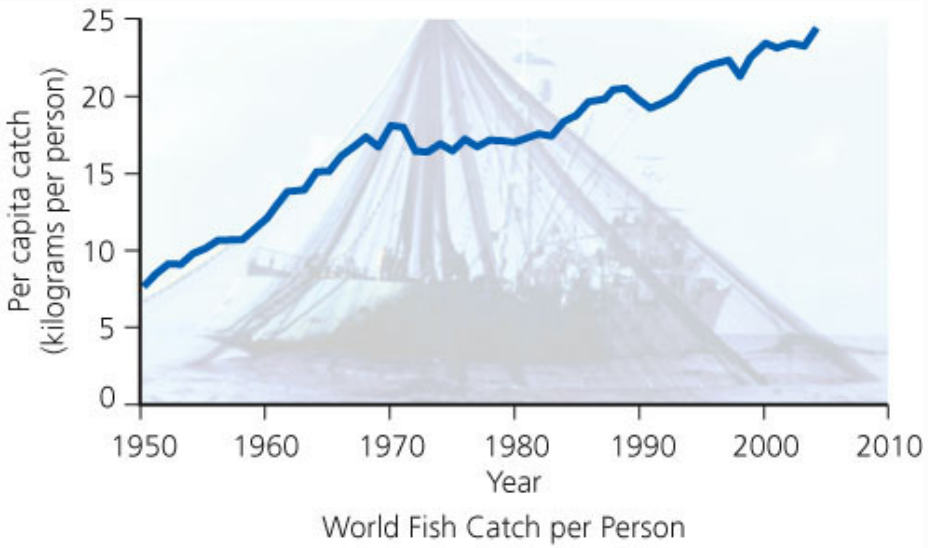
Fish and Shellfish Production Have Increased Dramatically

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

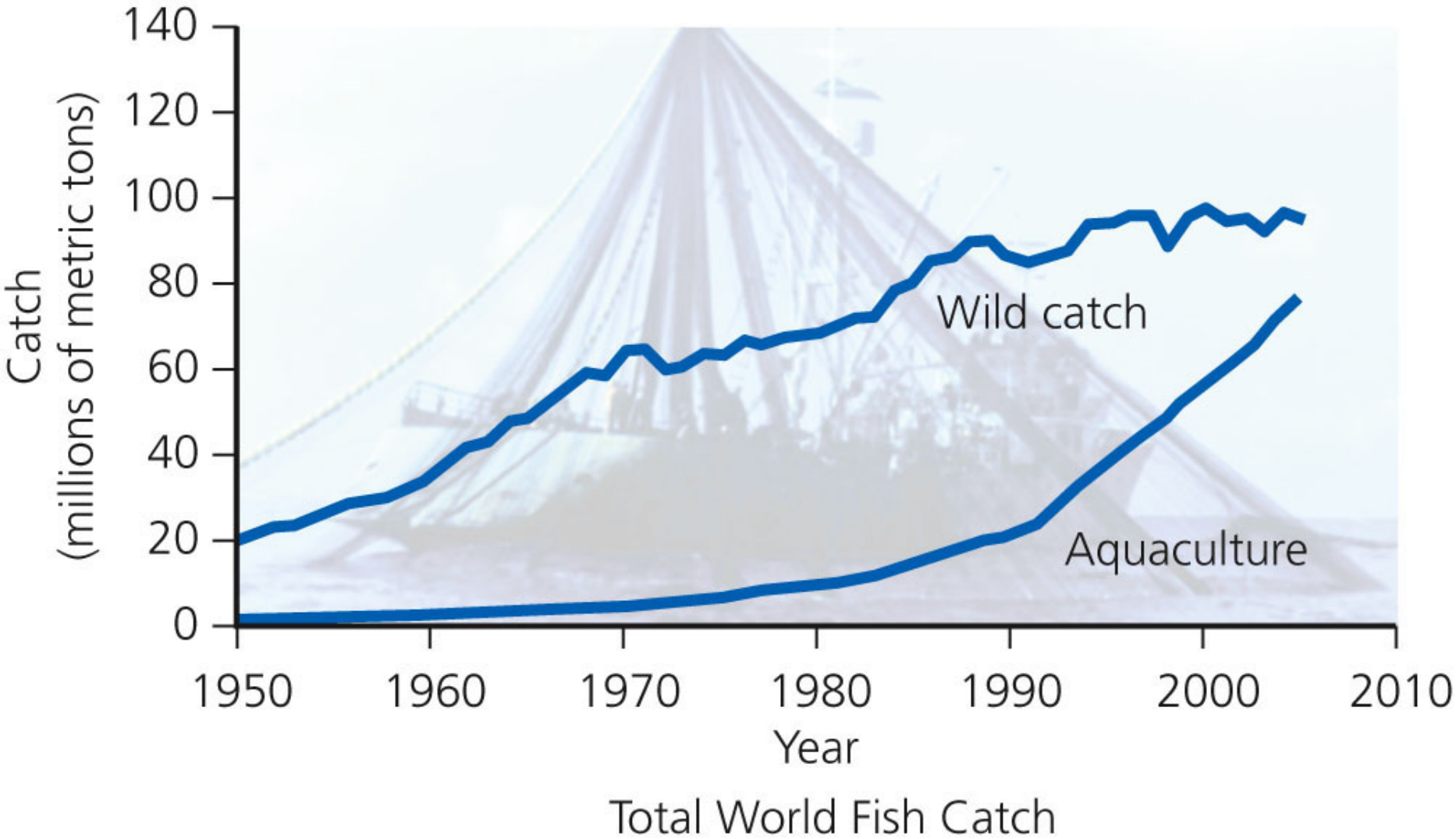
World Fish Catch, Including Both Wild Catch and Aquaculture



Total World Fish Catch

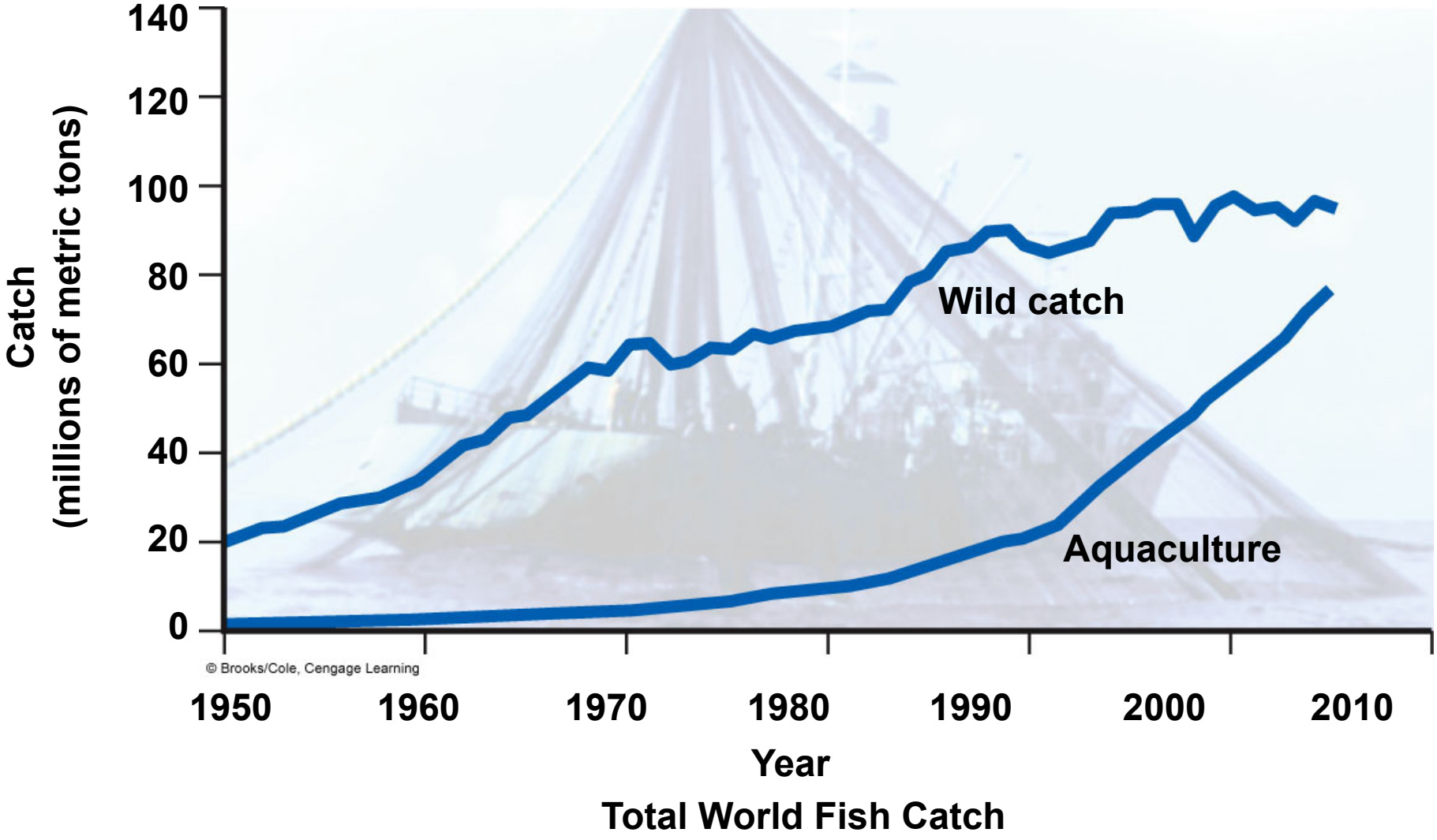


World Fish Catch per Person



Total World Fish Catch

Fig. 12-8a, p. 285



Total World Fish Catch

Fig. 12-8a, p. 285

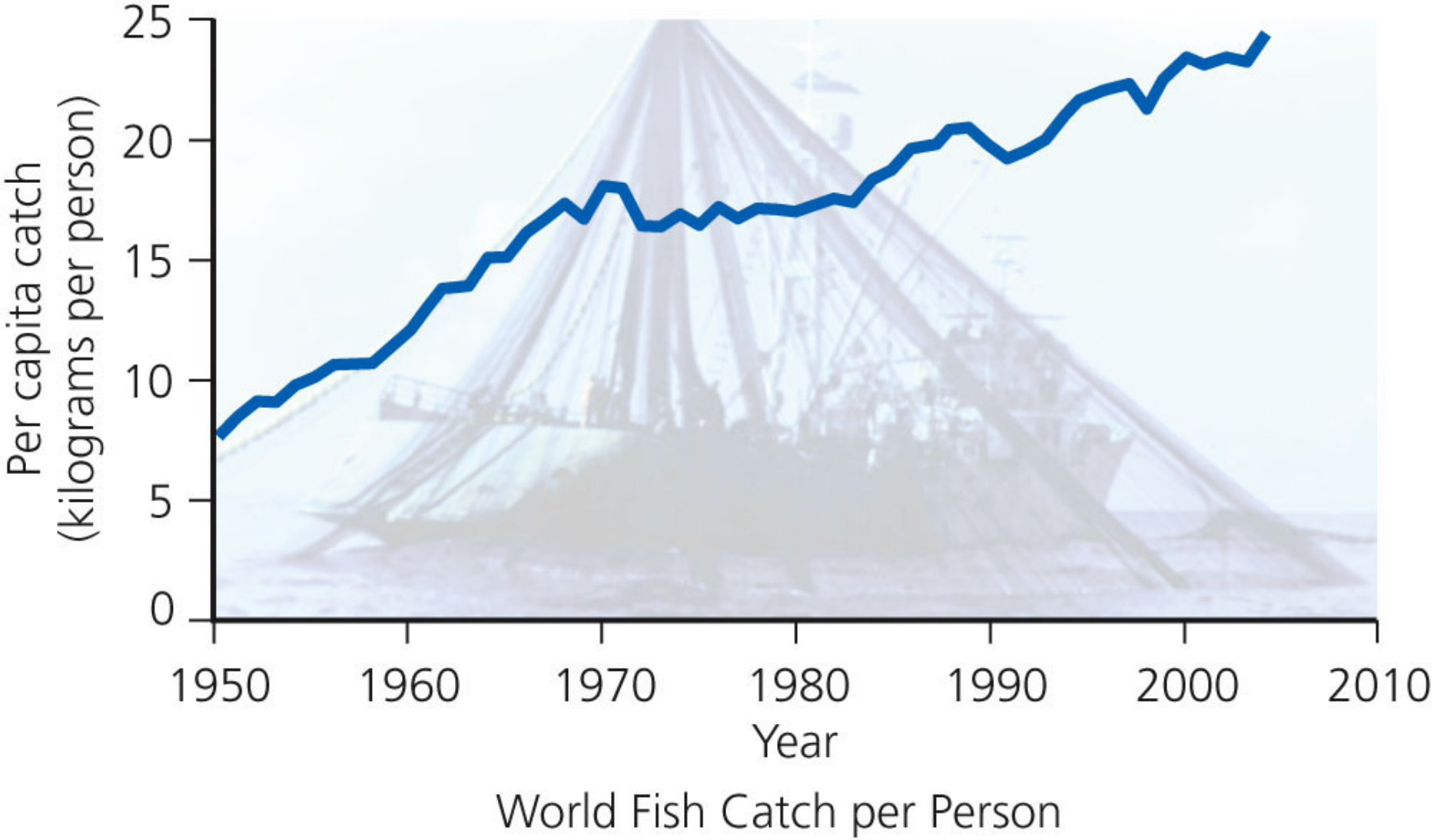
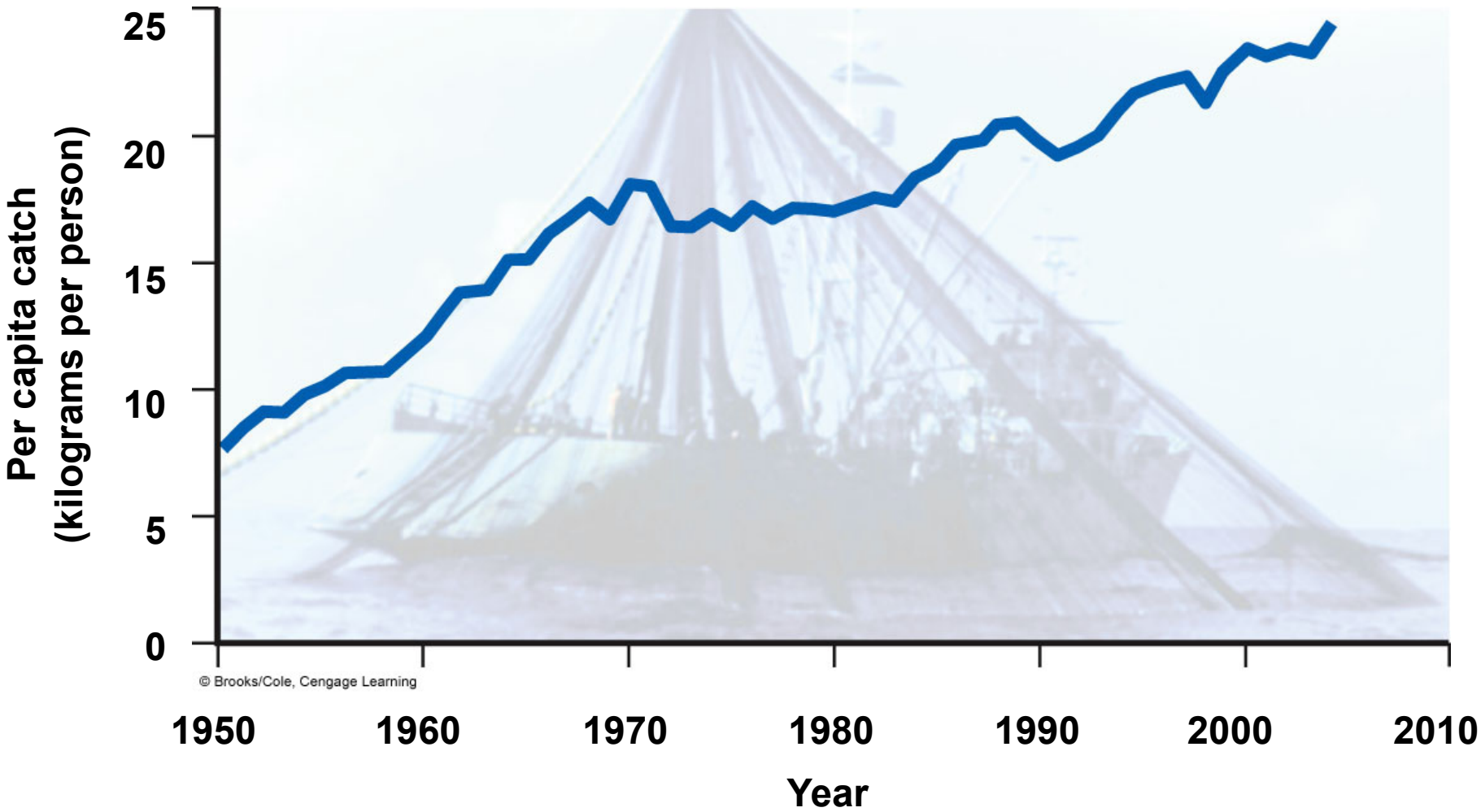


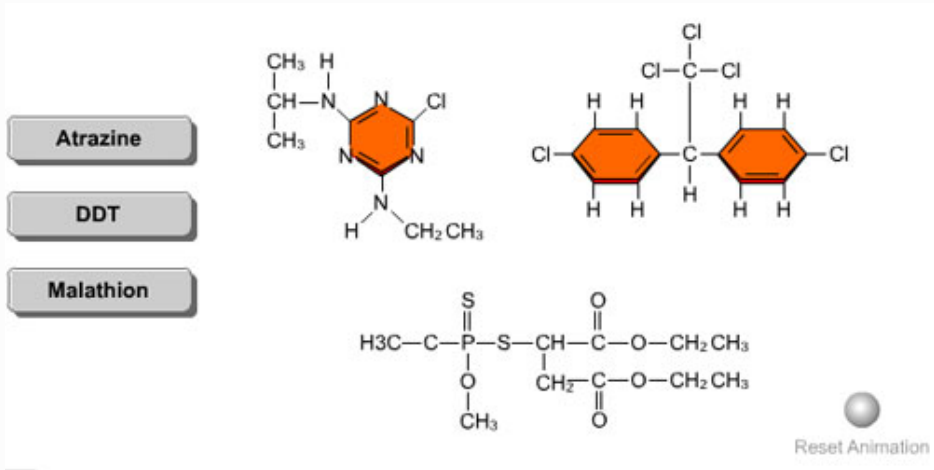
Fig. 12-8b, p. 285



World Fish Catch per Person

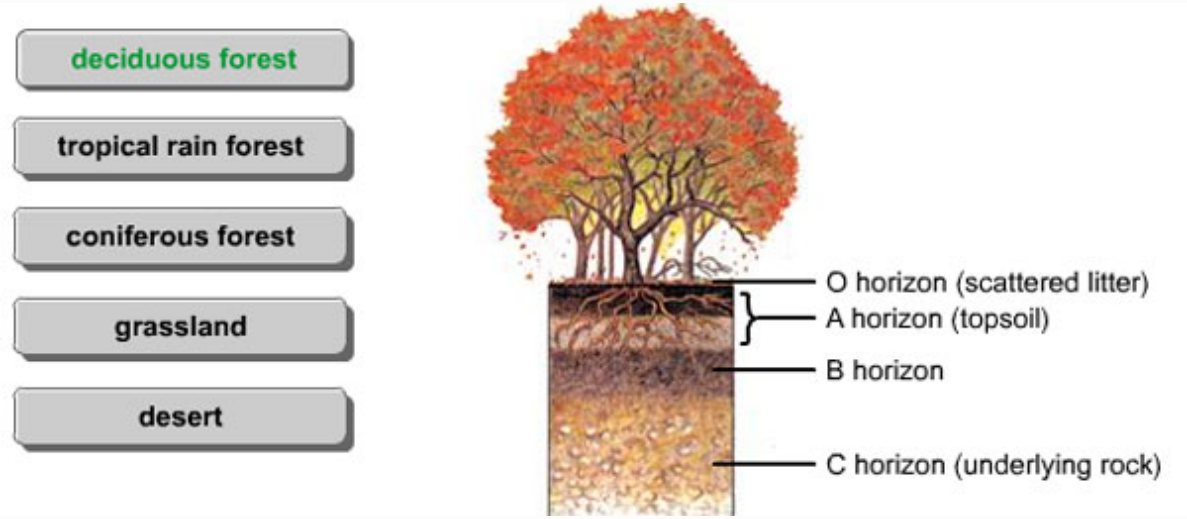
Fig. 12-8b, p. 285

Animation: Pesticide examples



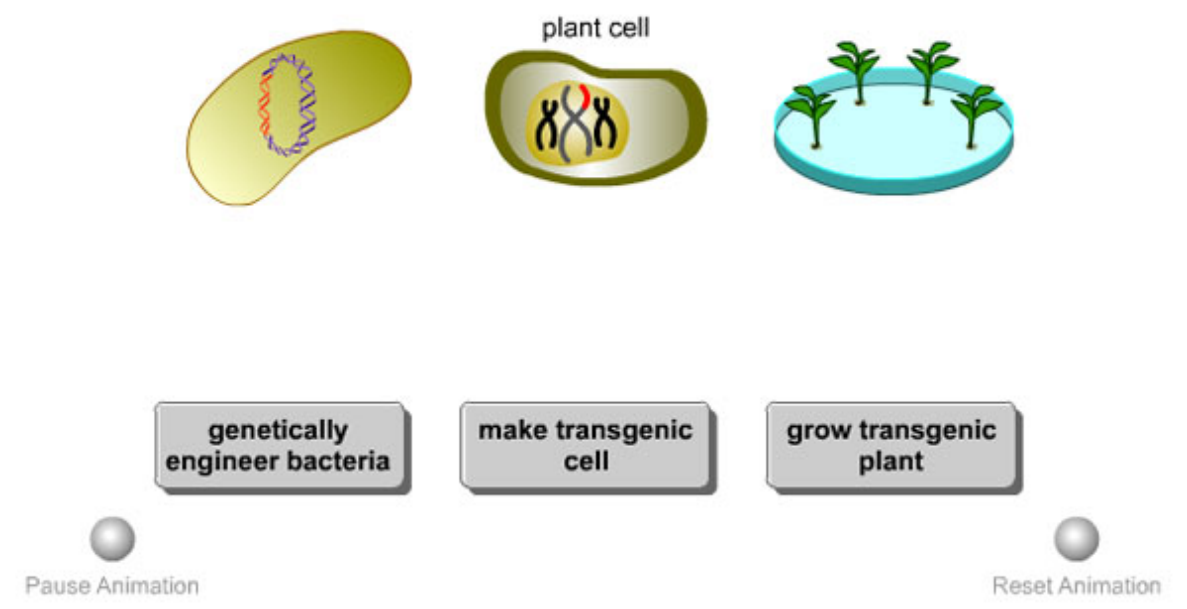
PLAY

Active Figure: Soil profile



PLAY

Animation: Transferring genes into plants



PLAY

12-3 What Environmental Problems Arise from Food Production?

- ***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.*

Producing 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

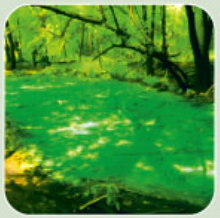
Erosion

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 (CO_2) from fossil fuel use

Greenhouse gas emissions (N_2O) from use of inorganic fertilizers

Greenhouse gas emissions of methane (CH_4) 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

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
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Air Pollution

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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

Fig. 12-9, p. 286

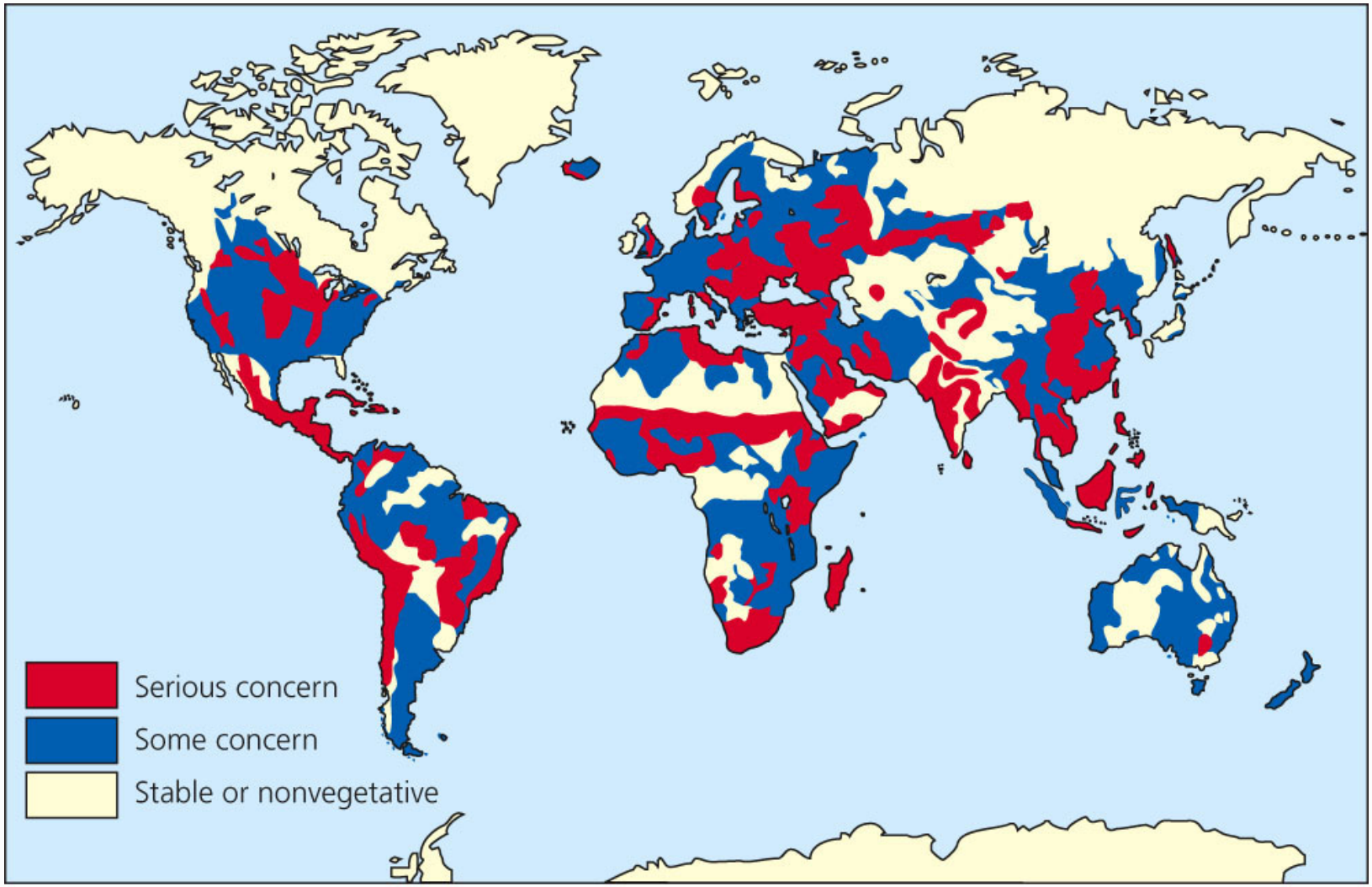
Topsoil Erosion Is a Serious Problem in Parts of the World

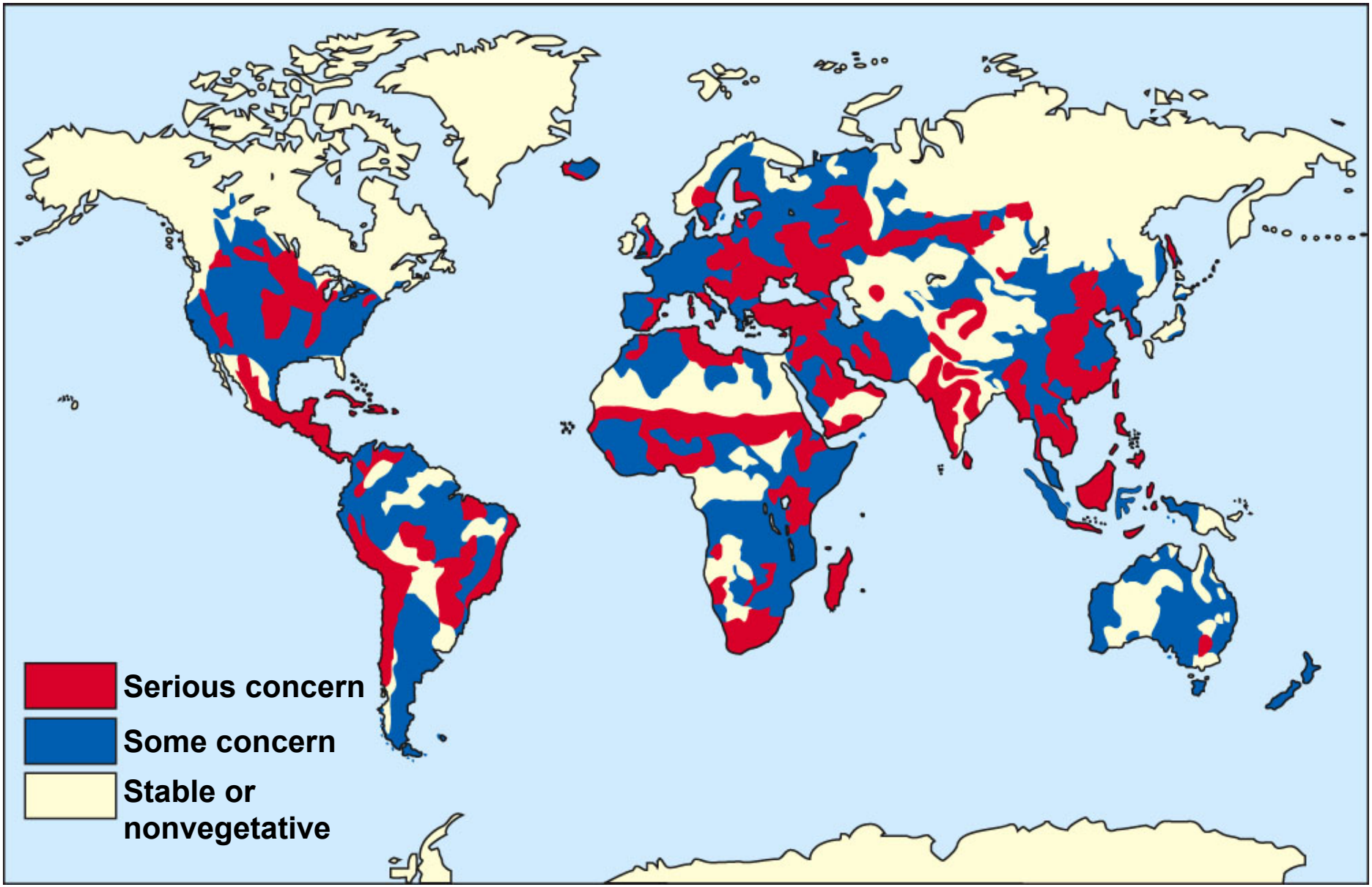
- **Soil erosion**
  - Natural causes
  - Human causes

- 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





Stepped Art

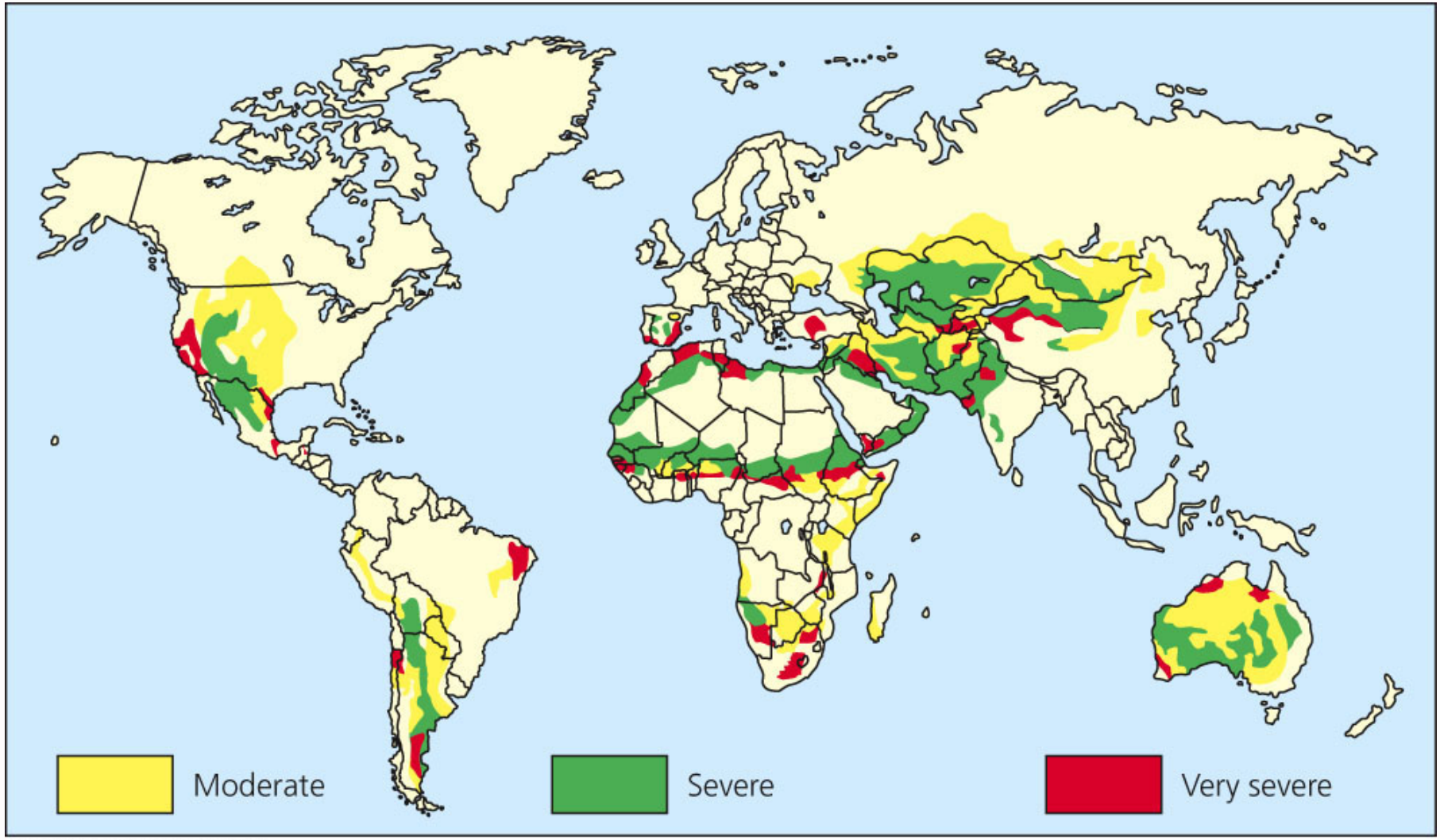
Fig. 12-11, p. 287

Drought and Human Activities Are Degrading Drylands

- **Desertification**
  - Moderate
  - Severe
  - Very severe
- Effect of global warming on desertification

Severe Desertification

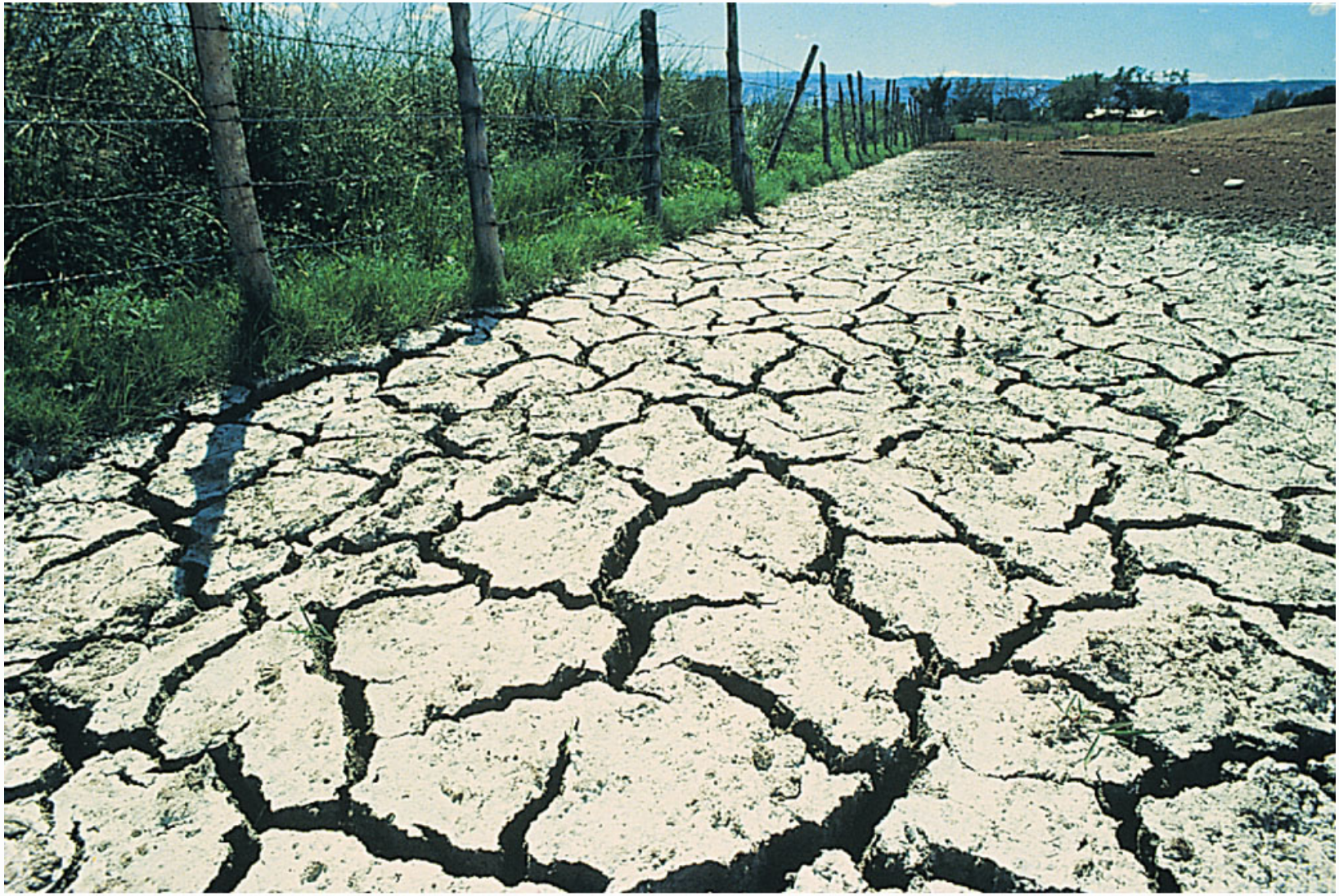
Natural Capital Degradation: Desertification of Arid and Semiarid Lands



Excessive Irrigation Has Serious Consequences

- Irrigation problems
  - **Salinization**
  - **Waterlogging**

Natural Capital Degradation: Severe Salinization on Heavily Irrigated Land



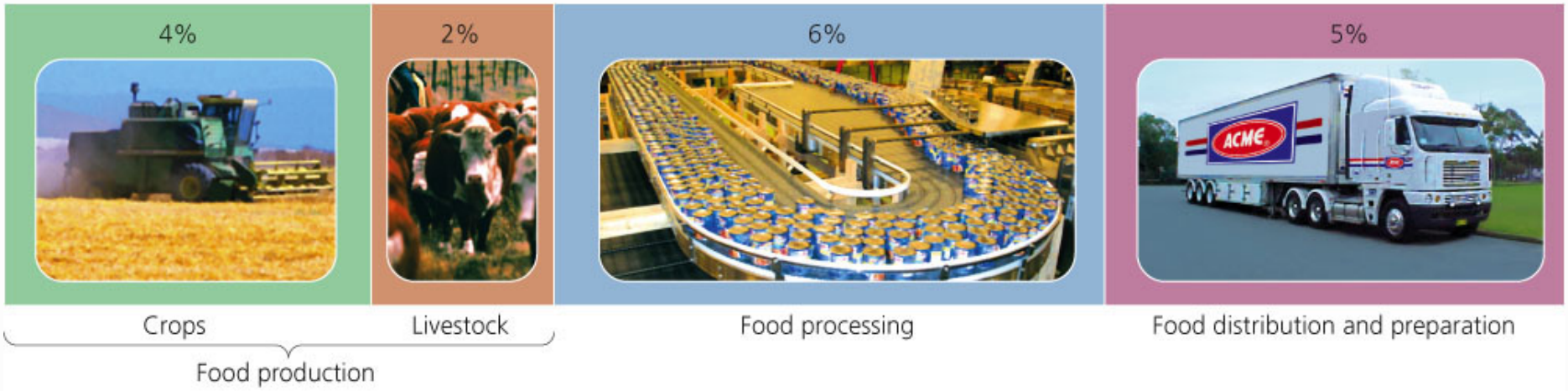
There May Be Limits to Expanding the Green Revolutions

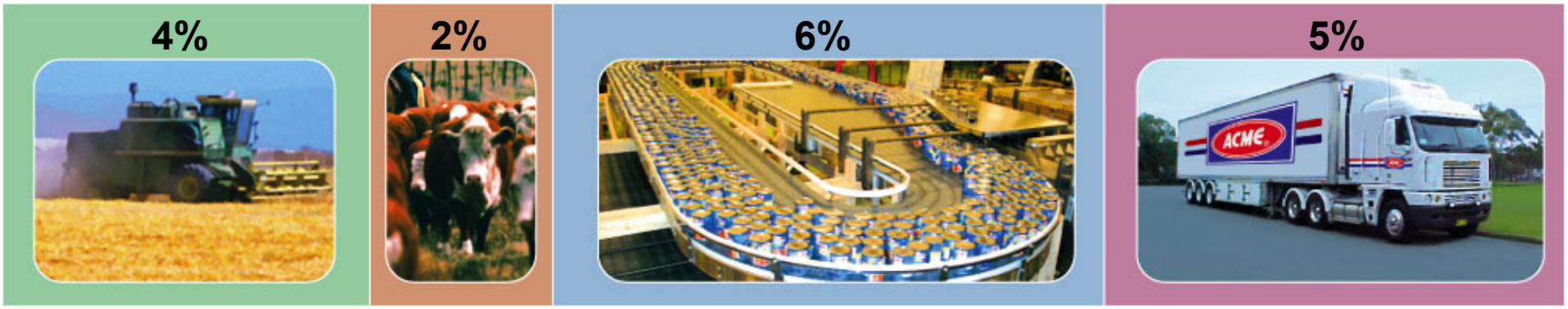
- Can we expand the green revolution by
  - Irrigating more cropland?
  - Improving the efficiency of irrigation?
  - Cultivating more land? Marginal land?
  - Using GMOs?
  - Multicropping?

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

Food production

Fig. 12-15, p. 290

There Is Controversy over Genetically Engineered Foods

- Pros
- Cons
- What about **chimeraplasty**?

Trade-Offs: Genetically Modified Crops and Foods

TRADE-OFFS

Genetically Modified Crops and Foods

Projected Advantages	Projected Disadvantages
Need less fertilizer	Irreversible and unpredictable genetic and ecological effects
Need less water	Harmful toxins in food from possible plant cell mutations
More resistant to insects, disease, frost, and drought	New allergens in food
Grow faster	Lower nutrition
Can grow in slightly salty soils	Increase in pesticide-resistant insects, herbicide-resistant weeds, and plant diseases
May need less pesticides	Can harm beneficial insects
Tolerate higher levels of herbicides	Lower genetic diversity
Higher yields	
Less spoilage	

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

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Projected Disadvantages

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Harmful toxins in food from possible plant cell mutations

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Lower nutrition

Increase in pesticide-resistant insects, herbicide- resistant weeds, and plant diseases

Can harm beneficial insects

Lower genetic diversity

Fig. 12-16, p. 291

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

TRADE-OFFS

Animal Feedlots

Advantages	Disadvantages
Increased meat production	Large inputs of grain, fish meal, water, and fossil fuels
Higher profits	Greenhouse gas (CO_2 and CH_4) emissions
Less land use	
Reduced overgrazing	Concentration of animal wastes that can pollute water
Reduced soil erosion	Use of antibiotics can increase genetic resistance to microbes in humans
Protection of biodiversity	

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 (CO_2 and CH_4) emissions

Concentration of animal wastes that can pollute water

Use of antibiotics can increase genetic resistance to microbes in humans

Fig. 12-17, p. 292

Producing Fish through Aquaculture Can Harm Aquatic Ecosystems

- Advantages
- Disadvantages

Trade-Offs: Aquaculture

TRADE-OFFS

Aquaculture

Advantages

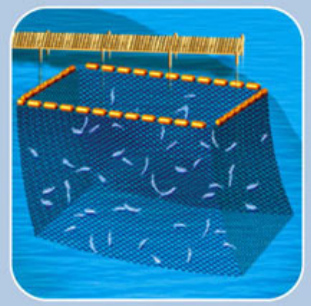
High efficiency

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

Advantages

High efficiency

High yield in small volume of water

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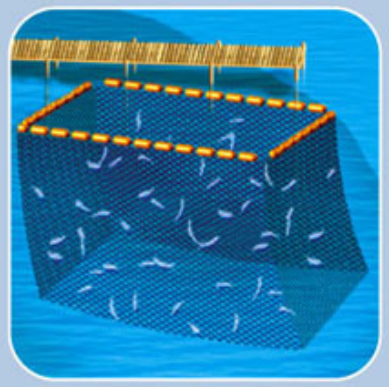


Disadvantages

Needs large inputs of land, feed, and water

Large waste output

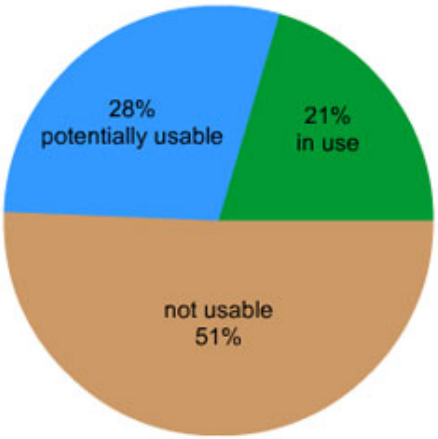
Can destroy mangrove forests and estuaries

Uses grain to feed some species

Dense populations vulnerable to disease

Fig. 12-18, p. 293

Animation: Land use



PLAY

12-4 How Can We Protect Crops from Pests More Sustainably?

- ***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

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

TRADE-OFFS

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Are expensive for farmers

Fig. 12-20, p. 295

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)

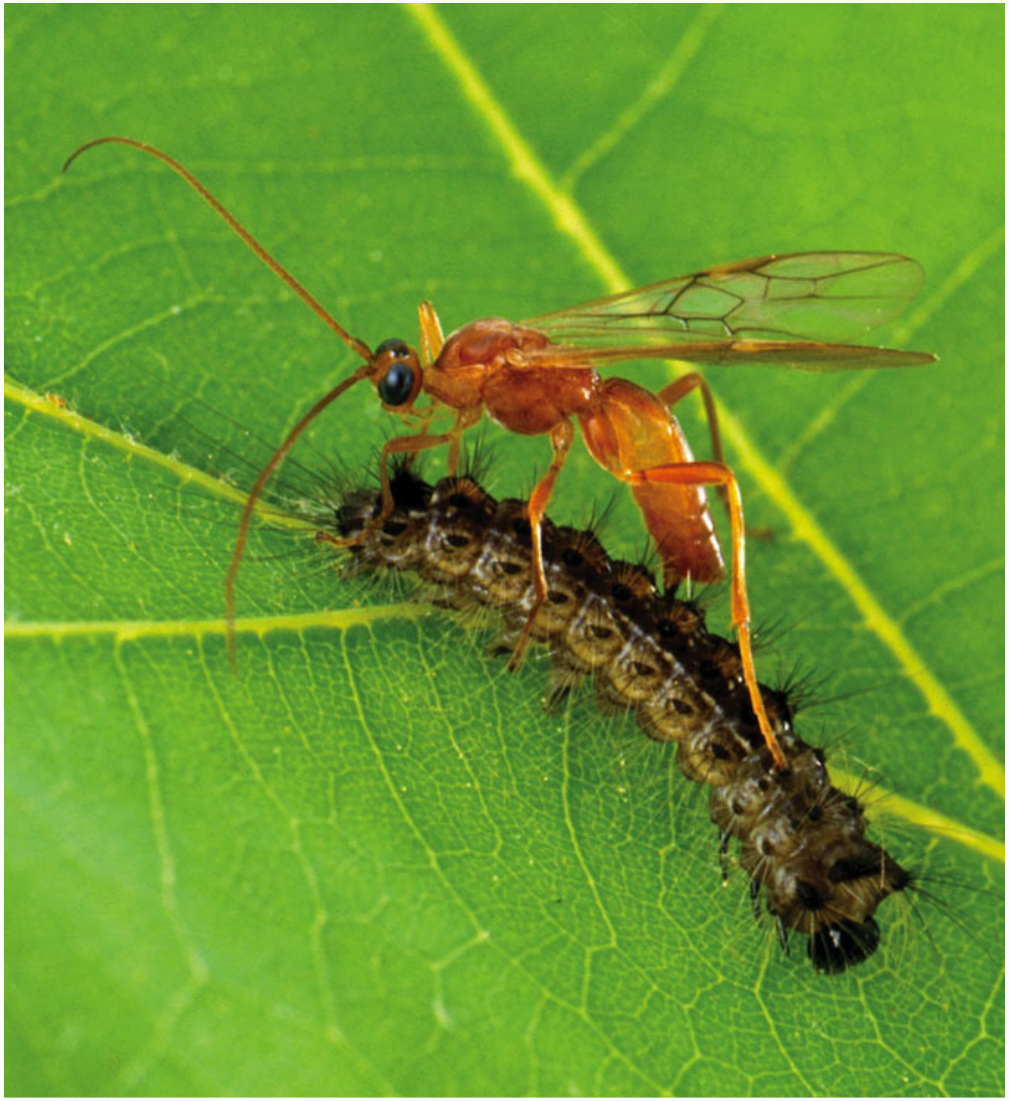
- Fool the pest
- Provide homes for pest enemies
- Implant genetic resistance
- Bring in natural enemies

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

12-5 How Can We Improve Food Security?

- ***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.*

12-6 How Can We Produce Food More Sustainably? (2)

- ***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**

Soil Conservation Methods

(a) Terracing

(b) Contour planting and strip cropping

(c) Alley cropping

(d) Windbreaks

(a) Terracing

Fig. 12-24a, p. 302

(a) Terracing

(b) Contour planting and strip cropping

Fig. 12-24b, p. 302

(b) Contour planting and strip cropping

Fig. 12-24b, p. 302

(c) Alley cropping

Fig. 12-24c, p. 302

(c) Alley cropping

Fig. 12-24c, p. 302

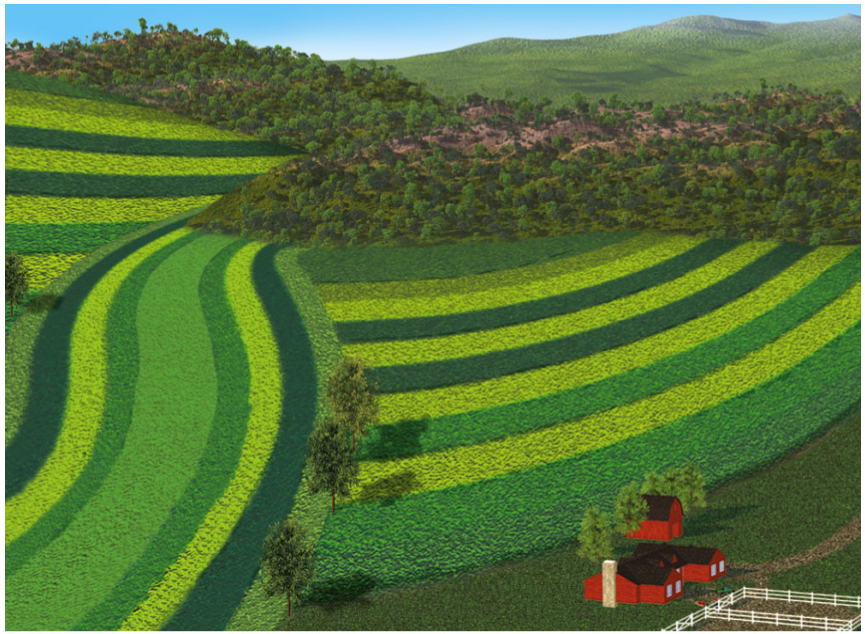
(d) Windbreaks

Fig. 12-24d, p. 302

(d) Windbreaks

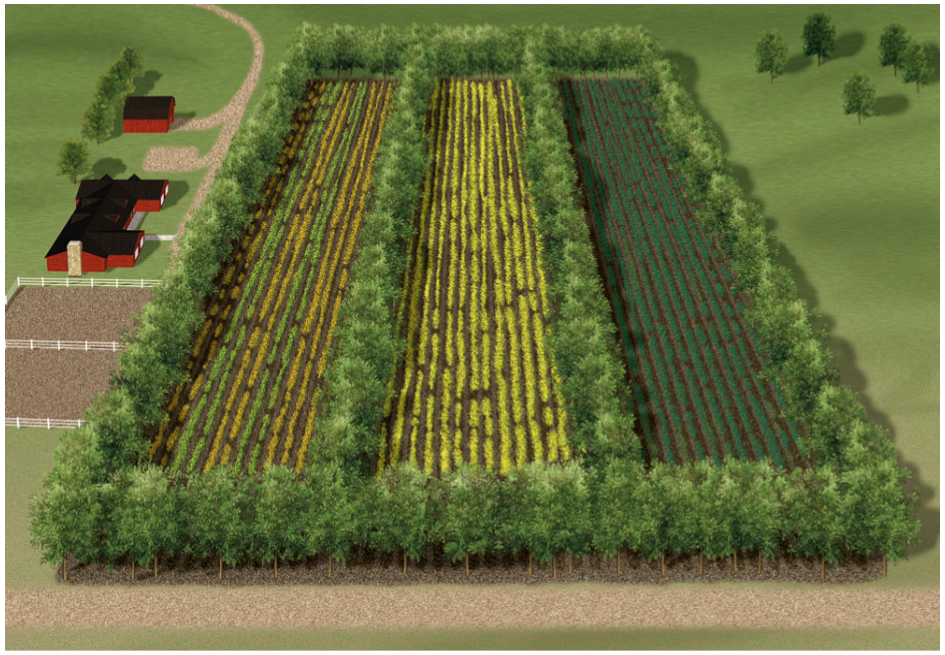
Fig. 12-24d, p. 302

(a) Terracing



(b) Contour planting and strip cropping

(c) Alley cropping



(d) Windbreaks

Stepped Art
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

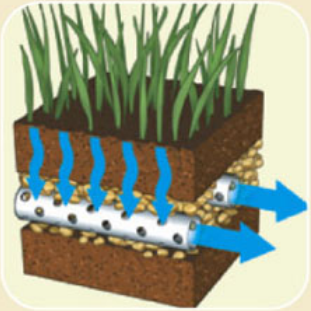
Solutions: Soil Salinization

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)

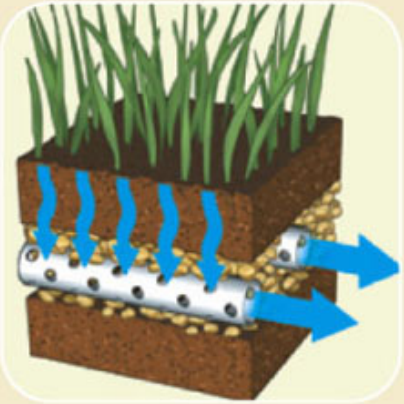
SOLUTIONS

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)

Fig. 12-28, p. 305

Practice More Sustainable Aquaculture

- Open-ocean aquaculture
  - Choose herbivorous fish
- Polyculture

Solutions: More Sustainable Aquaculture

SOLUTIONS

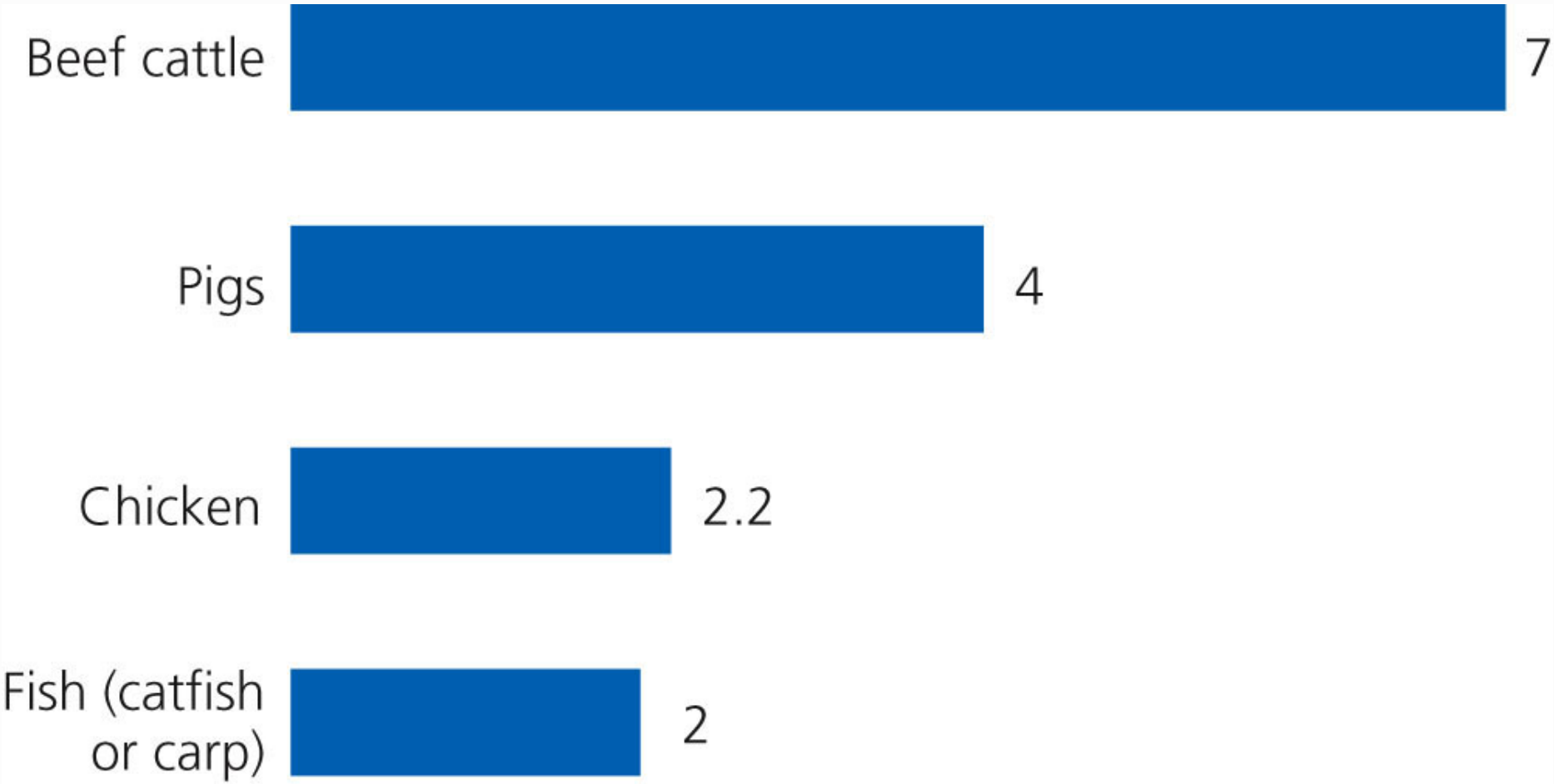
More Sustainable Aquaculture

- 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

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



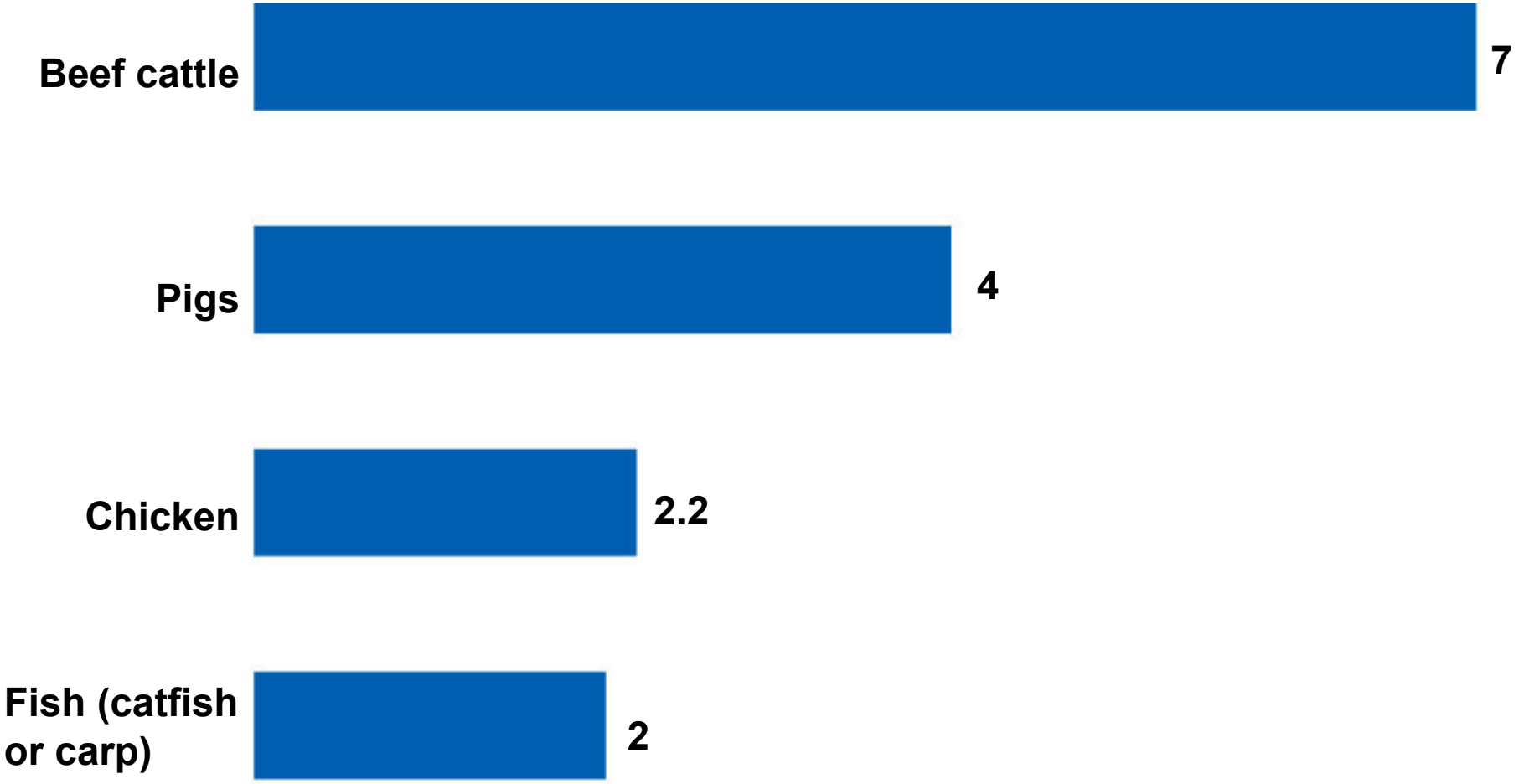


Fig. 12-30, p. 306

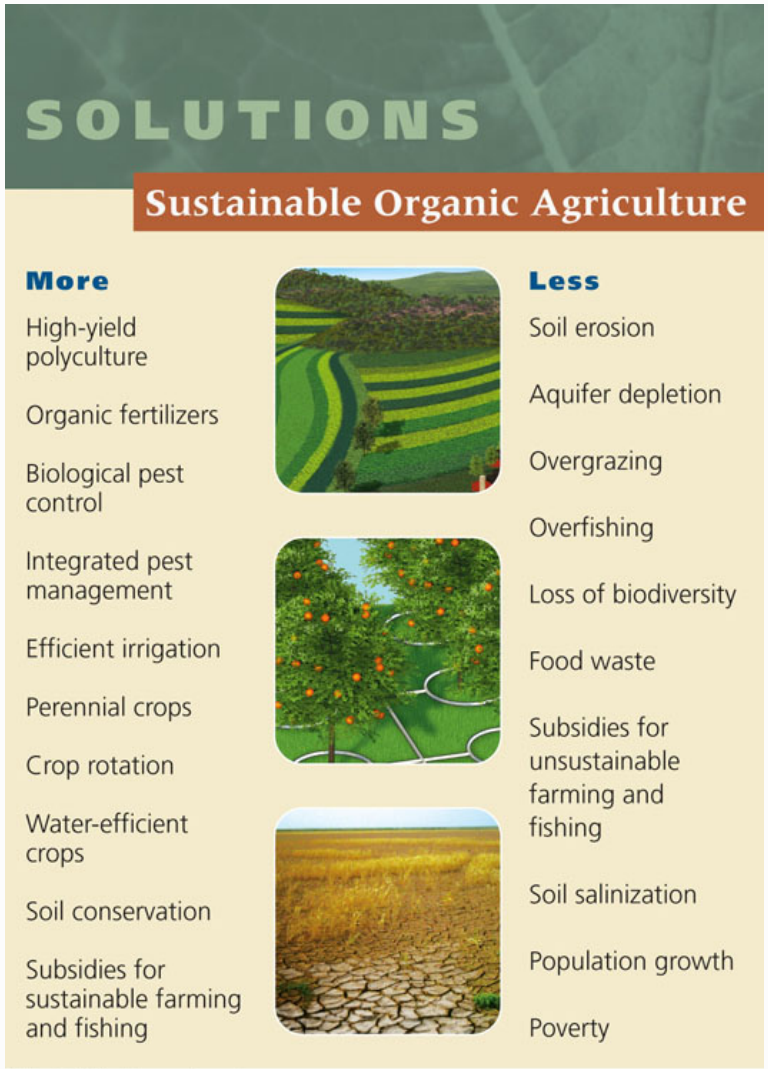
Shift to More Sustainable Agriculture (1)

- 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



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

Fig. 12-31, p. 307

Solutions: Organic Farming

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 CO_2 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

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 CO_2 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

Fig. 12-32, p. 308

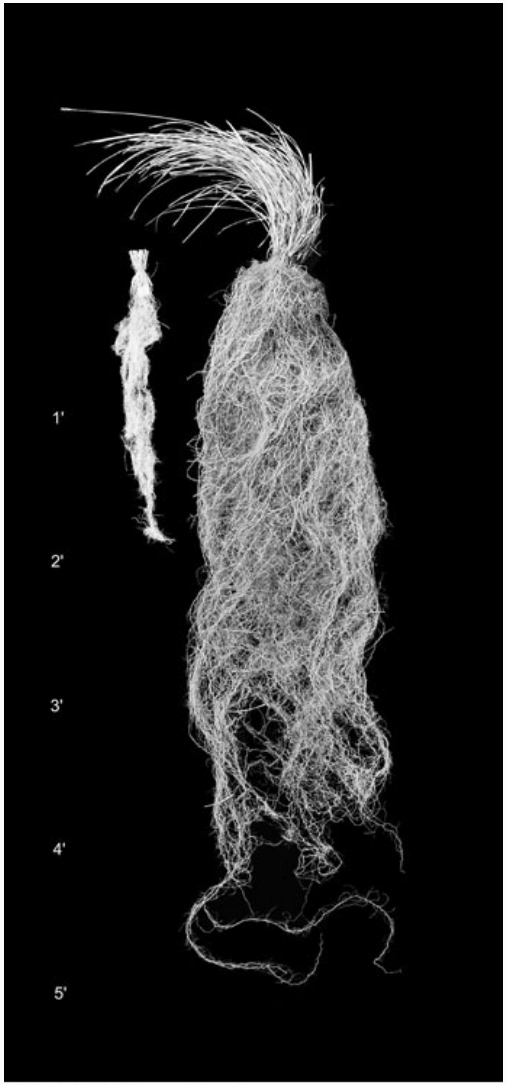
Science Focus: Scientists Are Studying Benefits and Costs of Organic Farming

- 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

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.