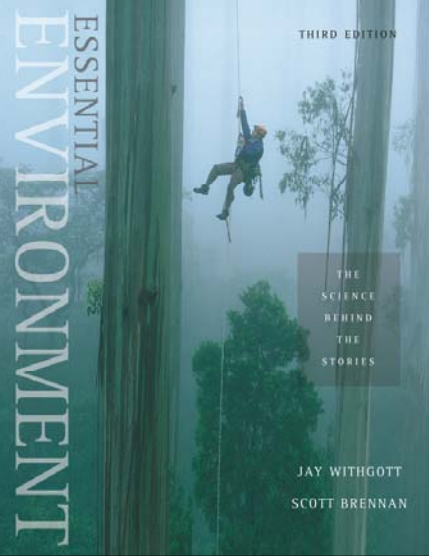


Chapter 7

Soil Agriculture and the Future of Food

PowerPoint® Slides prepared by Jay Withgott and Heidi Marcum



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Soil: the foundation for agriculture

- Land devoted to agriculture covers 38% of Earth's land surface.
- **Agriculture:** practice of raising crops and livestock for human use and consumption
- **Cropland:** land used to raise plants for human use
- **Rangeland or pasture:** land used for grazing livestock

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Impacts of agriculture

- **Traditional agriculture:** agriculture using human and animal muscle power, hand tools, and simple machines
- **Industrialized agriculture:** using large-scale mechanization and fossil fuels to boost yields
 - Also uses pesticides, irrigation, and fertilizers
- Mismanaged agriculture turns grasslands into deserts; removes forests; diminishes biodiversity; and pollutes soil, air, and water.
 - Fertile soil is blown and washed away.
 - Land suitable for farming is running out.
 - We must improve the efficiency of food production.

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Soil as a system

- **Soil:** a plant-supporting system consisting of disintegrated rock, organic matter, air, gases, nutrients
 - Dead and living microorganisms and decaying material
 - Bacteria, algae, earthworms, insects, and other animals



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Since soil is composed of living and non-living matter, it is considered an ecosystem.

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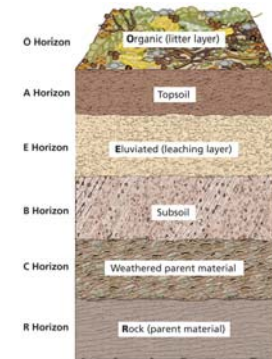
Soil formation is slow and complex

- **Parent material:** the base geologic material of soil
 - Lava, volcanic ash, rock, dunes, river sediments
 - **Bedrock:** the continuous mass of solid rock comprising the Earth's crust
- **Weathering:** the physical, chemical, or biological processes that break down rocks to form soil
- Biological activity also contributes to soil formation.
 - Through deposition, decomposition, and accumulation of organic matter
 - **Humus:** a dark, spongy, crumbly mass of material formed by partial decomposition

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A soil profile consists of horizons

- **Horizon:** each layer of soil
- **Soil profile:** the cross-section of soil as a whole
- Soil profiles can have 6 horizons.
 - **Topsoil (A horizon):** inorganic and organic material that is the most nutritive for plants
 - **Leaching:** dissolved particles move down through horizons



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Soils display great variety

- Topsoil is vital for agriculture.
 - But unsustainable practices reduce the soil's fertility and ability to hold water.
- Soil scientists classify soils using color, texture, structure, and pH.
 - **Loam:** soil with an even mixture of pore and particle sizes
 - The soil most suitable for agriculture is a loamy mixture with a pH close to neutral that is workable and can hold nutrients.

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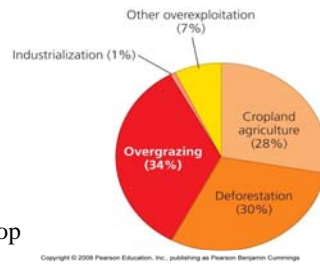
Regional differences in soils affect agriculture

- Rainforest soils are much less productive than temperate grasslands.
 - Rain leaches minerals and nutrients, reducing their accessibility to roots.
 - **Swidden agriculture:** cultivation of a plot for a few years and then letting it regrow into forest
- Temperate grasslands have lower rainfall and less nutrient leaching.
 - Nutrients remain within reach of plants.
 - These soils can be repeatedly farmed with appropriate farming techniques.

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Soil degradation has many causes

- Poor agricultural practices reduce soil's ability to support life.
 - We are cultivating more unsuitable lands.
- Soil degradation results from agriculture, deforestation, and overgrazing.
- Over the past 50 years, soil degradation has reduced global crop production by 13%.



Problems affecting soil productivity include erosion, desertification, salinization, waterlogging, nutrient depletion, structural changes, and pollution.

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Erosion carries soil away

- **Erosion:** the removal of material from one place to another by wind or water
 - **Deposition:** the arrival of eroded material at its new location
- Flowing water deposits sediment in river valleys and deltas.
 - Floodplains are excellent for farming.
- Erosion removes topsoil, the most valuable soil layer.
 - Erosion occurs faster than new soil is formed.
 - It increases through: excessive tilling, overgrazing, and clearing forests.
 - Plant communities protect soil from erosion.

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Erosion and desertification are global problems

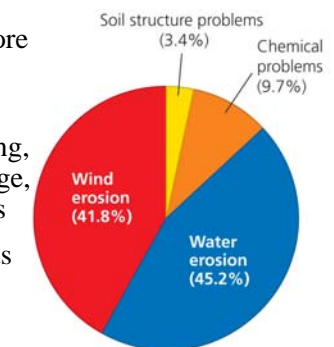
- Humans are the primary cause of erosion.
 - It is occurring at unnaturally high rates.
- More than 19 billion ha (47 billion acres) of the world's croplands suffer from erosion and other soil degradation.
- In Africa, erosion over the next 40 years could reduce crop yields by half.
 - Coupled with rapid population growth, some observers describe the future of agriculture as a crisis situation.

In the U.S., erosion has declined, but farmlands still lose 5 tons of soil for every ton of grain harvested.

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Desertification

- **Desertification:** a loss of more than 10% soil productivity
 - Erosion, soil compaction, forest removal, overgrazing, salinization, climate change, depletion of water sources
- Most prone areas = arid lands



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Desertification has high costs

- Desertification affects 1/3 of the planet's land area.
 - In over 100 countries
- 50 million people may be displaced within 10 years due to desertification from climate change.
- Costs tens of billions of dollars each year
 - China loses over \$6.5 billion/year
- Deserts are expanding and massive dust storms are occurring worldwide.

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The Dust Bowl

- In the late 19th and early 20th centuries, settlers arrived in Oklahoma, Texas, Kansas, New Mexico, and Colorado
- Grew wheat, grazed cattle
 - Removed vegetation
- A drought in the 1930s made conditions worse.
- Thousands of farmers left their land and had to rely on governmental help.



(a) Kansas dust storm, 1930s
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(b) Dust Bowl region
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The Soil Conservation Service

- The U.S. Congress passed the Soil Conservation Act of 1935, creating the Soil Conservation Service (SCS).
- The SCS works with farmers to develop conservation plans for farms.
 - The earliest example of interdisciplinary approaches to environmental problem solving
 - Serves as a model for similar efforts elsewhere

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Protecting soil: crop rotation and contour farming

- **Crop rotation:** alternating the crops grown from one season or year to the next
 - Minimizes erosion, pest damage
 - Wheat or corn and soybeans
- **Contour farming:** plowing furrows sideways across a hillside, perpendicular to its slope, to prevent gullies



(a) Crop rotation
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(b) Contour farming
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Protecting soil: terracing and intercropping

- **Terracing:** level platforms are cut into steep hillsides, sometimes with raised edges
 - A “staircase” to contain water
- **Intercropping:** planting different types of crops in alternating bands or other spatially mixed arrangements
 - Increases ground cover



(c) Terracing
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(d) Intercropping
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Protecting soil: shelterbelts and no-till farming

- **Shelterbelts or Windbreaks:** rows of trees or other tall, perennial plants that are planted along the edges of fields to slow the wind
- **No-till farming:** furrows are cut in the soil, a seed is dropped in, and the furrow is closed



(e) Shelterbelts
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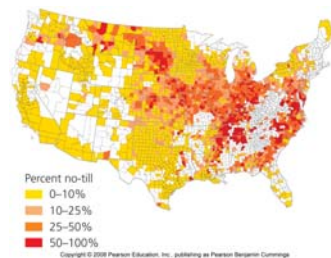


(f) No-till farming
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Pros and cons of no-till farming

- Almost half of U.S. farmland uses no-till farming.
- Benefits: reduced soil erosion, greater crop yields, enhanced soils
- Negatives: increased use of herbicides and fertilizers
- But **green manure** (dead plants used as fertilizer) and rotating crops minimize these negatives



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Irrigation: boosted productivity, but problems, too

- **Irrigation:** artificially providing water to support agriculture
 - Unproductive regions become farmland
- **Waterlogging:** over-irrigated soils
 - Water suffocates roots
- **Salinization:** the buildup of salts in surface soil layers
 - Worse in arid areas



(a) Conventional irrigation
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Salinization inhibits production of 20% of all irrigated cropland, costing more than \$11 billion/year.

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Preventing salinization

- It is easier and cheaper to prevent salinization than to fix it.
- Do not plant water-guzzling crops in sensitive areas.
- Irrigate with low-salt water.
- Irrigate efficiently, supplying only water that the crop requires.
 - **Drip irrigation** targets water directly to plants.



(b) Drip irrigation
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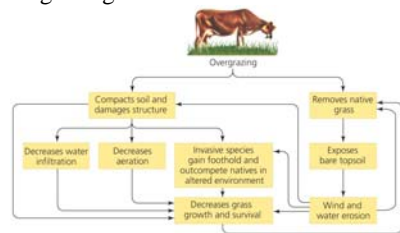
Fertilizers boost yields but cause problems

- **Fertilizer:** substances that contain essential nutrients
- **Inorganic fertilizers:** mined or synthetically manufactured mineral supplements
- **Organic fertilizers:** the remains or wastes of organisms
 - Manure, crop residues, fresh vegetation
 - **Compost:** produced by decomposition of organic matter
- Inorganic fertilizer use has skyrocketed and boosted production.
 - But overapplying fertilizer can ruin the soil and cause severe pollution.
 - Runoff causes eutrophication in nearby water systems.
 - Nitrates leach through soil and contaminate groundwater.

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Overgrazing causes soil degradation

- **Overgrazing:** too many animals eat too much of the plant cover
 - A leading cause of soil degradation
- Government policies (few rules and inexpensive fees) facilitate overgrazing.



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The world's 3.4 billion livestock degrade rangeland and costs \$23.3 billion/year

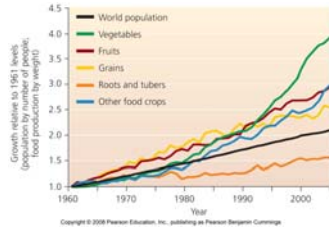
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Some policies promote soil conservation

- Every 5 to 6 years, Congress passes a farm bill.
 - Many provisions require farmers to adopt soil conservation plans before getting subsidies.
- **Conservation Reserve Program (1985)**
 - Pays farmers to plant highly erodible land with trees and grasses instead of crops
 - Each dollar invested saves 1 ton of topsoil.
 - Generates income for farmers
 - Improves water quality and provides habitat for wildlife
 - With current higher food prices, many farmers are planting more acres.

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Today, we are producing more food per person



- The human population is expected to reach 9 billion by 2050.
- Food production currently exceeds population growth.
- But 850 million people in developing countries do not have enough to eat.

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Some people starve, but others eat too much



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-
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• receive too few calories per day
 • few nutrients in food
 • starves to death.
 • too many calories each day
 • junk food and don't exercise.
 • 600 million people are obese.

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Food security

- **Food security:** the guarantee of adequate and reliable food supply to all people at all times
 - We have reduced hunger by half since 1970.
 - Through fossil fuels, irrigation, fertilizers, pesticides, more agricultural land, more productive crops, and livestock
- **Monoculture:** the uniform planting of a single crop
 - Industrialized agriculture requires that vast fields are planted with single types of crops.
- In recent years, grain production has decreased.

Since 1985, world grain production per person has fallen by 9%.

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The green revolution

- Uses technologies to dramatically increase crop output
 - Stunning success transformed agriculture in developing countries
- Spread to the developing world in the 1940s with wheat, rice, corn
- Depended on large amounts of:
 - Synthetic fertilizers
 - Chemical pesticides
 - Irrigation
 - Heavy equipment



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The green revolution had costs and benefits

- From 1900 to 2000, cultivated area increased 33%, while energy inputs increased 80 times!
- Positive effects on natural resources: reduced pressure to convert more natural land to cropland
 - Prevented some deforestation and habitat conversion
- Negative effects on natural resources:
 - Pollution and reduced biodiversity
 - Erosion, salinization and desertification
 - Increased susceptibility to crop diseases
- Today, soil quality is declining, resulting in lower yields.

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Pests and pollinators

- **Pest:** any organism that damages valuable crops
- **Weed:** any plant that competes with crops
- **Pesticides:** poisons that target pest organisms
 - **Insecticides:** target insects
 - **Herbicides:** target plants
 - **Fungicides:** target fungi
- 400 million kg (900 million lbs.) of pesticides are applied in the U.S. each year.
 - 75% of this is applied to agricultural land.
 - Usage is increasing in developing countries.

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Common pesticides

- *More than \$32 billion is spent on pesticides each year in the world.*
 - *1/3 of this is spent in the U.S.*

TABLE 10.1 Most Commonly Used Pesticides* in Agriculture in the United States

Active ingredient [†]	Type of pesticide	Millions of kg applied per year
Glyphosate	Herbicide	39–41
Atrazine	Herbicide	34–36
Metam sodium	Fumigant	26–28
Acetochlor	Herbicide	14–16
2,4-D	Herbicide	13–15
Malathion	Insecticide	9–11
Methyl bromide	Fumigant	9–11
Dichloropropene	Fumigant	9–11
Metolachlor-s	Herbicide	9–11
Metolachlor	Herbicide	7–10

*Includes only "conventional pesticides" used in agriculture, and not other types such as disinfectants and wood preservatives.

[†]Includes only active ingredients, not additional ingredients such as oil, sulfur, and sulfuric acid.

Data from Kiehy, T., et al. 2004. *Pesticides industry sales and usage: 2000 and 2001 market estimates*. Washington, DC: U.S. Environmental Protection Agency.

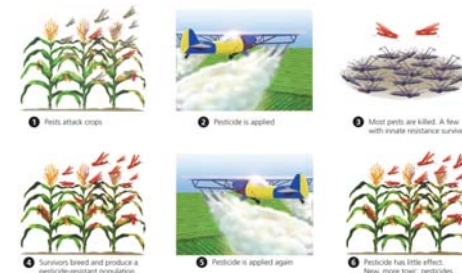
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Resistance to pesticides

- Some individuals are genetically immune to a pesticide.
 - They survive and pass these genes to their offspring.
- Pesticides stop being effective.
 - **Evolutionary arms race:** chemists increase chemical toxicity to compete with resistant pests

In 2008, 550 species were resistant to 300 pesticides.



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Biological control

- **Biological control (Biocontrol):** uses a pest's natural predators to control the pest
 - Leads to steep reductions in chemical pesticide use
 - Cactus moths control invasive prickly pear cactus
 - **Bacillus thuringiensis (Bt):** soil bacteria that kills many pests



(a) Before cactus moth introduction
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(b) After cactus moth introduction
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Biocontrol involves risks

- No one can predict the effects of an introduced species.
- The agent may become invasive and harm non-target organisms.
 - Cactus moths are eating rare Florida cacti.
- Removing a biocontrol agent is harder than halting pesticide use.
 - The harm done by biocontrol agents may be permanent.

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Integrated Pest Management (IPM)

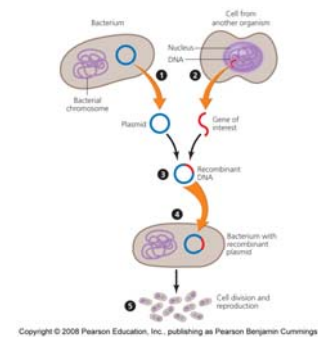
- IPM uses multiple techniques to suppress pests.
 - Biocontrol
 - Chemicals, when necessary
 - Population monitoring
 - Habitat alteration
 - Crop rotation and transgenic crops
 - Alternative tillage methods
 - Mechanical pest removal

Within 4 years of using IPM in Indonesia, rice yields rose 13%, and \$179 million was saved by phasing out subsidies.

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Genetically modified organisms

- Relentless population growth demands still more agricultural .
- **Genetic engineering:** laboratory manipulation of genetic material
- **Genetically modified organisms:** organisms that have been genetically engineered by...
- **Recombinant DNA:** DNA created from multiple organisms



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Biotechnology is impacting our lives

- **Biotechnology:** the material application of biological science to create products derived from organisms
- **Transgenic organism:** an organism that contains DNA from another species
 - **Transgenes:** the genes that have moved between organisms
- Biotechnology has helped us create medicines, clean up pollution, and dissolve blood clots.

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Genetic engineering versus agricultural breeding

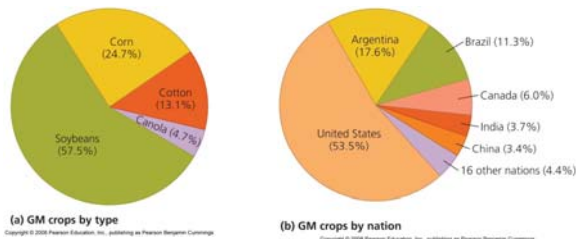
- Artificial selection has influenced the genetic makeup of livestock and crops for thousands of years.
- Proponents of GM crops say GM foods are safe.
- Critics of GM foods say:
 - Traditional breeding uses genes from the same species.
 - Selective breeding deals with whole organisms, not just genes.
 - In traditional breeding, genes come together on their own.

Traditional breeding changes organisms through selection, while genetic engineering is more like the process of mutation.

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Biotechnology is changing our world

- GM foods have become big business.
- Many traits engineered into crops make them more efficient and economical for farmers to grow.
 - Most U.S. soybeans, corn, cotton, and canola are genetically modified.



Globally, in 2007, more than 12 million farmers grew GM foods on 114 million ha of farmland, producing \$6.9 billion worth of crops.

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What are the impacts of GM crops?

- As GM crops expanded, scientists and citizens became concerned.
 - Dangerous to human health
 - Escaping transgenes could pollute ecosystems and damage non-target organisms.
 - Pests could evolve resistance to the supercrops.
 - Interbred with closely related wild plants
 - Could ruin the integrity of native ancestral races

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Many aspects of GM foods remain unknown

- Supporters make the following points:
 - Millions of Americans eat GM foods without signs of harm.
 - Consequences of interbreeding remain debatable.
 - Herbicide-resistant crops encourage no-till farming.
 - GM crops may require less fertilizer and irrigation.
- Critics argue that we should adopt the **precautionary principle** — don't do any new action until it's understood.

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The GM debate involves more than science

- Ethical issues play a large role.
 - People don't like “tinkering” with the food supply.
 - Some fear domination of the food supply by large agrobiotech corporations (i.e., Monsanto, Dow).
 - Research is funded by corporations that will profit if GM foods are approved for use.

The GM industry is driven by market considerations of companies selling proprietary products.

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Different cultures view GM foods differently

- Europeans are uneasy about GM foods.
 - European governments demand that GM foods are labeled.
- U.S. consumers have largely accepted GM crops.
 - They don't even realize their foods contain GM products.
- The future of GM foods will hinge on social, economic, legal, and political factors, as well as scientific ones.

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Preserving crop diversity: insurance against failure

- The genetic diversity of ancestral varieties of crops must be preserved.
 - Any single catastrophe can wipe out an entire monocrop.
 - These varieties contain genes that could confer resistance to diseases and pests.
- **Seed banks:** institutions that preserve seed types as a kind of living museum of genetic diversity
 - Seeds are collected, preserved, and periodically planted.



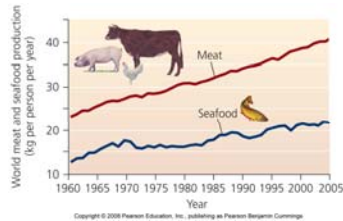
(a) Traditional food plants of the Desert Southwest
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Britain's Royal Botanic Garden's Millennium Seed Bank holds more than 1 billion seeds.

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Eating animal products has significant impacts

- As wealth and commerce increase, so does consumption of meat, milk, and eggs.
 - Global meat production has increased fivefold.
 - Per capita meat consumption has doubled.



Today, over 20 billion domestic animals are produced for food; the typical American eats over 200 kg (440 lbs) of meat per year.

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Feedlot agriculture

- Feedlots (factory farms):** also called **Concentrated Animal Feeding Operations (CAFOs)**
 - Huge warehouses or pens designed to deliver energy-rich food to animals living at extremely high densities
 - Over ½ of the world's pork and poultry come from feedlots.



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Debeaked chickens spend their lives in cages; U.S. farms can house hundreds of thousands of chickens in such conditions.

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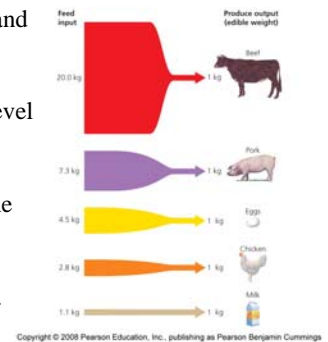
The benefits and drawbacks of feedlots

- The benefits of feedlots include:
 - Greater production of food
 - Unavoidable in countries with high levels of meat consumption, like the U.S.
 - They take livestock off the land and reduce the impact that they would have on it.
- Drawbacks of feedlots include:
 - Contributions to water and air pollution
 - Poor waste containment causes outbreaks of disease.
 - Heavy uses of antibiotics to control disease

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Energy choices through food choices

- Our food choices impact energy and land use.
- 90% of energy is lost every time energy moves from one trophic level to the next.
- Eating lower on the food chain increases the number of people the Earth can support.
- Some animals convert grain into meat more efficiently than others.

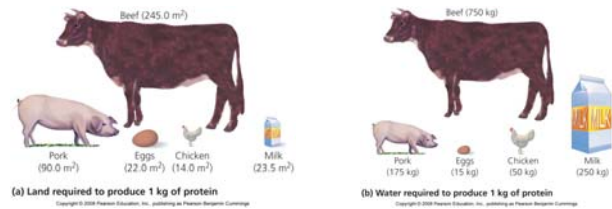


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Environmental ramifications of eating meat

- Land and water are needed to raise food for livestock.
- Producing eggs and chicken meat requires the least space and water.
 - Producing beef requires the most space and water.

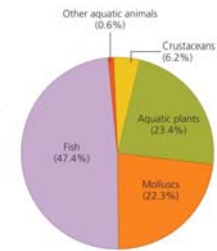


When we choose what to eat, we also choose how we use resources.

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Aquaculture

- Wild fish populations are plummeting.
 - Technology and increased demand
- **Aquaculture:** raising aquatic organisms for food in a controlled environment (“fish farm”)
 - Aquatic species are raised in open-water pens or land-based ponds.
- The fastest-growing type of food production
 - Provides a third of the world’s fish
 - Most widespread in Asia



(a) World aquaculture production by groups
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The benefits and drawbacks of aquaculture

- | | |
|--|---|
| <ul style="list-style-type: none"> • Benefits: <ul style="list-style-type: none"> - A reliable protein source - Sustainable - Increases food security - Reduces fishing pressure on wild fish stocks - Energy efficient | <ul style="list-style-type: none"> • Drawbacks: <ul style="list-style-type: none"> - Diseases can occur, requiring expensive antibiotics - Reduces food security - Large amounts of waste - Growing grain to feed fish is inefficient - Farmed fish may escape and introduce disease into the wild |
|--|---|



A larger, transgenic salmon (top) vs. a smaller wild salmon

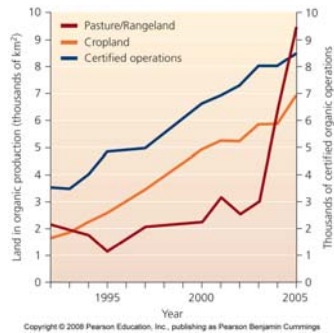
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Sustainable Agriculture

- Industrial agriculture may seem necessary, but less-intensive agricultural methods may be better in the long run.
- **Sustainable agriculture:** does not deplete soil, pollute water, or decrease genetic diversity
- **Low-input agriculture:** uses smaller amounts of pesticide, fertilizers, growth hormones, water, and fossil fuel energy than industrial agriculture
- **Organic agriculture:** uses no synthetic fertilizers, insecticides, fungicides, or herbicides
 - Relies on biological approaches (composting and biocontrol)

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Organic agriculture is increasing



- People debate the meaning of the word “organic.”
 - Organic Food Production Act (1990) establishes national standards for organic products.
 - The USDA issued criteria in 2000 by which food could be labeled organic.
- The market for organic food is increasing.
 - Farmers in all 50 states and 130 nations practice commercial organic farming.

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The benefits of organic farming

- For farmers:
 - Lower input costs, enhanced income from higher-value products, reduced chemical pollution, and soil degradation
- For consumers:
 - Concern about pesticide’s health risks
 - A desire to improve environmental quality
- Government initiatives can encourage organic farming.
 - Conversion often means a temporary loss in income for farmers.

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Organic agriculture succeeds in cities

- Increasing numbers of farmers and consumers are supporting local small-scale agriculture.
 - Farmers’ markets in North America provide fresh, local produce in season.
- **Community-supported agriculture:** consumers pay farmers in advance for a share of their yield
 - Consumers get fresh food.
 - Farmers get a guaranteed income.



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Conclusion

- Intensive commercial agriculture has substantial negative environmental impacts.
 - Industrialized agriculture has relieved pressures on the land and resources.
- If our planet will be able to support 9 billion humans, we must shift to sustainable agriculture.
 - Biological pest control; organic agriculture; pollinator protection; preservation of native crop diversity; aquaculture; and careful, responsible genetic modification of food

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