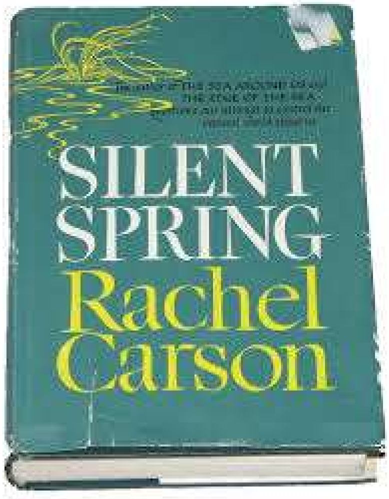
SOIL POLLUTION

DISCLAIMER

"The nation that destroys its soil destroys itself." Franklin D. Roosevelt

- Nobody cared much about soil at the beginning of the environmental movement

- Environmental scientists eventually realized → almost everything ends up in soil or sediments → currently large area of interest



THE SOIL SYSTEM

- Formation of soil from the parent material (bedrock): mechanical weathering of rocks by temperature changes, abrasion, wind, moving water, glaciers, chemical weathering activities and lichens.
- Under ideal climatic conditions, soft parent material may develop into 1 cm of soil within 15 years.

- Soil consists of mineral matter, organic matter, air, and water
  - Dead and living microorganisms, and decaying material
  - Bacteria, algae, earthworms, insects, mammals, amphibians, and reptiles

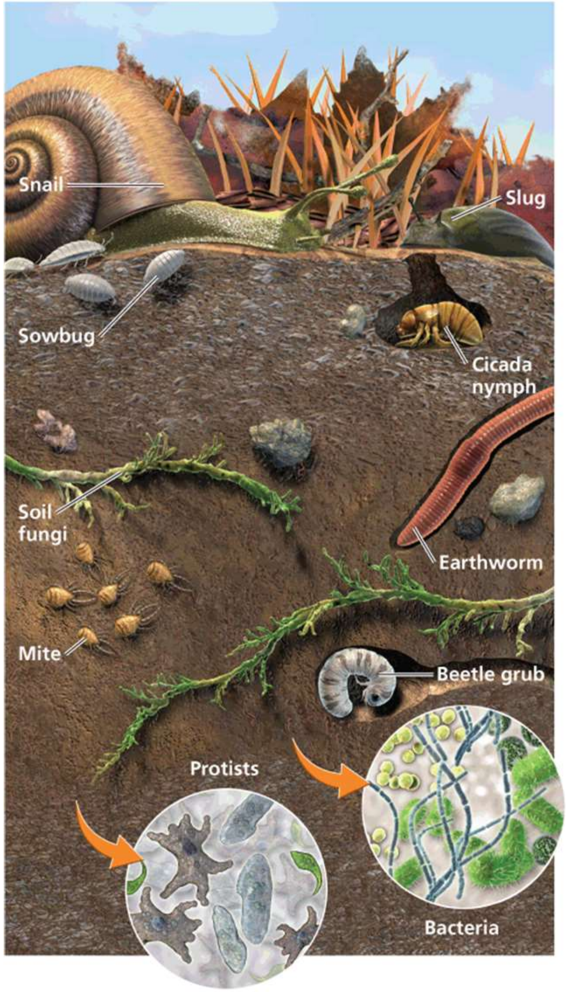


FIGURE 7.1
Soil is a complex mixture of organic and inorganic components and is full of living organisms whose actions help keep it fertile. Entire ecosystems exist in soil. Most soil organisms, from bacteria to fungi to insects to earthworms, decompose organic matter. Many, such as earthworms, also help to aerate the soil.

SOIL: COMPLEX DYNAMIC SYSTEM

- Soil consists of mostly mineral matter with varying proportions of organic matter, the rest is pore space taken up by air, water, and other soil gases
- **Parent material** = the base geologic material of soil
  - Determines the starting composition of the soil
- **Organic matter** includes living and dead microorganisms as well as decaying plant and animal material
- **Water** – is not pure, contains dissolved minerals and organics and is important for support of plant growth
- **Air** – soil air is not the same as air we breathe
- Soil can have an influence on a region's ecosystem

SOIL: FORMATION

- Soil formation begins when parent material is exposed to the effects of the atmosphere, hydrosphere, and biosphere
  - Parent material can be lava, volcanic ash, rock, dunes or most commonly, 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
  - **Physical (mechanical) =** wind and rain, no chemical changes in the parent material
  - **Chemical =** substances chemically interact with parent material
  - **Biological =** organisms break down parent material

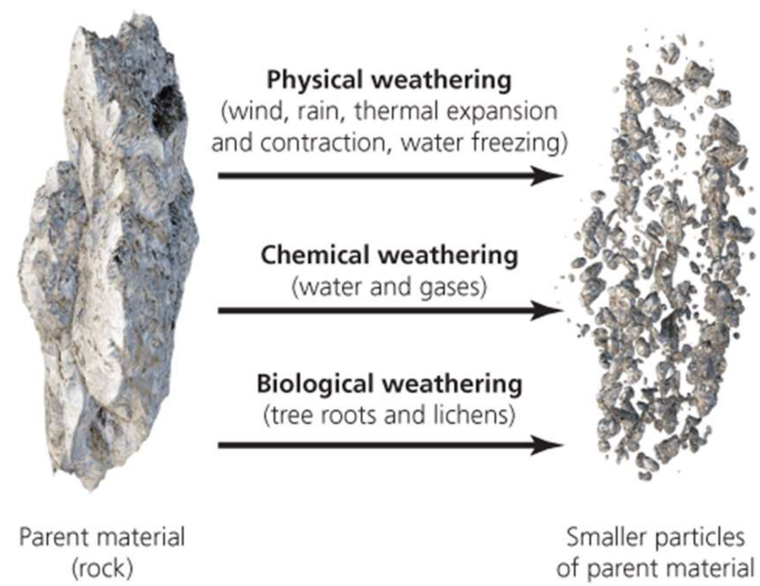


FIGURE 7.2
The weathering of parent material is the first step in soil formation. Rock is broken down into finer particles by physical, chemical, and biological processes.

SOIL: FORMATION

- Biological activity includes deposition, decomposition, and accumulation of organic matter
  - **Humus** = a dark, spongy, crumbly mass of material formed by partial decomposition
- **Erosion** = the dislodging and movement of soil by wind or water
  - Occurs when vegetation is absent
  - When deposited elsewhere referred to as **sediment**

SOIL: FORMATION

It can take anywhere from 500 to 100 years to produce 1 cm of natural topsoil, depending on local conditions.

Given this very long renewal time, is soil truly a renewable resource?

How should the very long renewal time influence soil management?

SOIL: KEYWORDS

- **Horizon** = each layer of soil
- **Soil profile** = the cross-section of soil as a whole
- **Topsoil** = inorganic and organic material most nutritive for plants
- **Leaching** = dissolved particles move down through horizons
- **Litter** = surface deposits of leaves, branches, mosses, animal waste

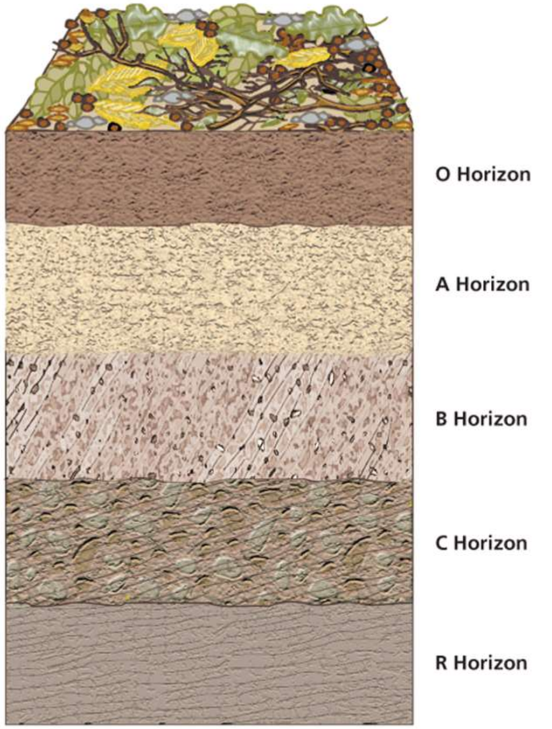
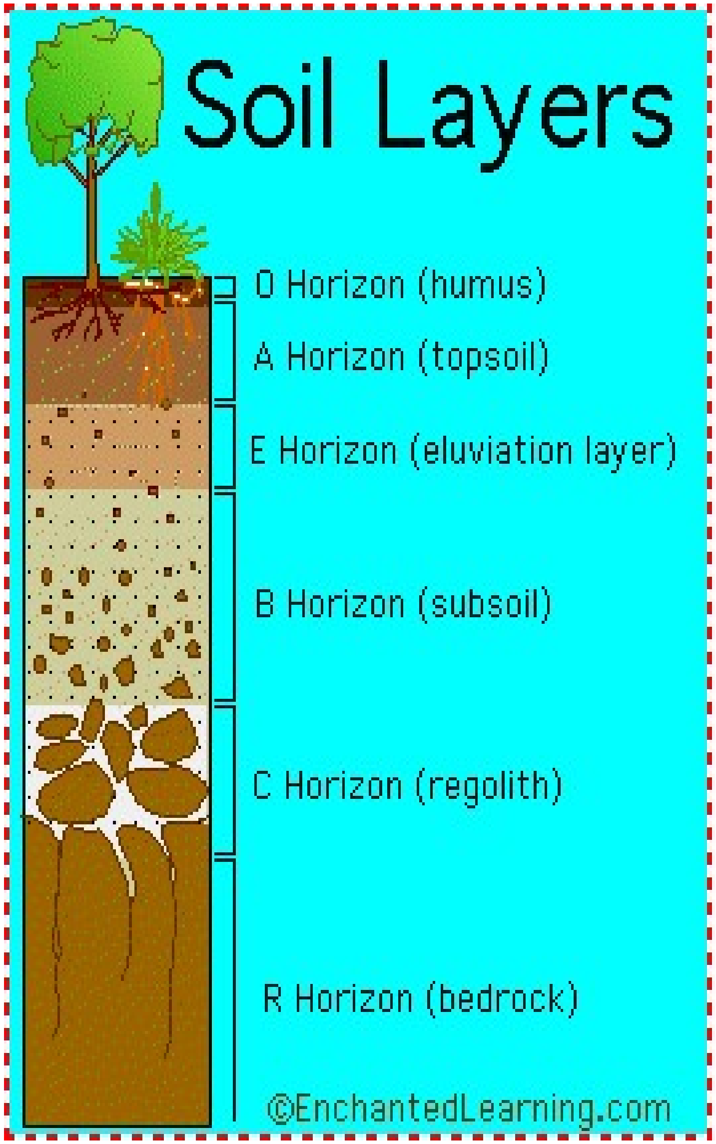


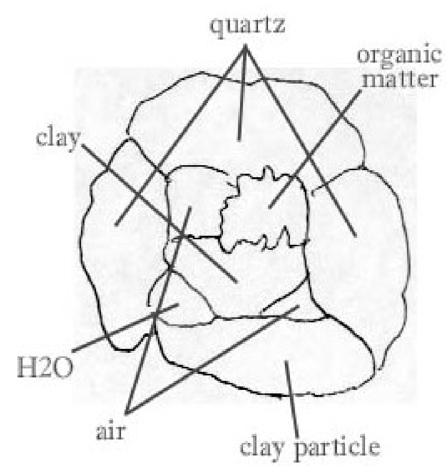
FIGURE 7.3
Mature soil consists of layers, or horizons, that have different compositions and characteristics. The number and depth of horizons vary from place to place as a result of the mix of soil-forming factors at the location, producing different soil profiles. The O horizon consists mostly of organic matter deposited by organisms. The A horizon (or *topsoil*), is the uppermost mineral horizon and consists of some organic material mixed with mineral components. Materials tend to be leached from the A horizon and deposited in the B horizon. The C horizon consists largely of weathered material that is still identifiable as parent rock, and which may overlie an R horizon of pure parent material.

- **O-horizon:** freshly-fallen & partially-decomposed leaves, twigs, animal waste, fungi & organic materials. Colour: brown or black.
- **A-horizon:** humus/partially decomposed organic matter & some inorganic mineral particles. darker & looser than the deeper layers.
- **O & A-horizon:** contain a large amount of bacteria, fungi, earthworms, small insects, forms complex food web in soil, recycles soil nutrients, & contribute to soil fertility.
- **B-horizon /(subsoil):** less organic material & fewer organisms than A- horizon.
- **C-horizon:** consists of broken-up bedrock, does not contain any organic materials. Chemical composition helps to determine pH of soil & also influences soil's rate of water absorption & retention.
- R-horizon: The unweathered rock (bedrock) layer that is beneath all the other layers



WHAT IS SOIL?

- Mix of rock, weathered mineral, and organic matter
- 95% is mineral matter by dry weight (but only 45% by volume)
- Lots of air space (20—30% by volume) → lots of room for infiltration/retention of pollutant's



- Soils classified into various categories using:
  - Color
  - Texture
  - Structure
  - pH

SOIL: CLASSIFICATION

- **Soil color** = indicates its composition and fertility
  - Black or dark brown = rich in organic matter
  - Pale gray or white = indicates leaching

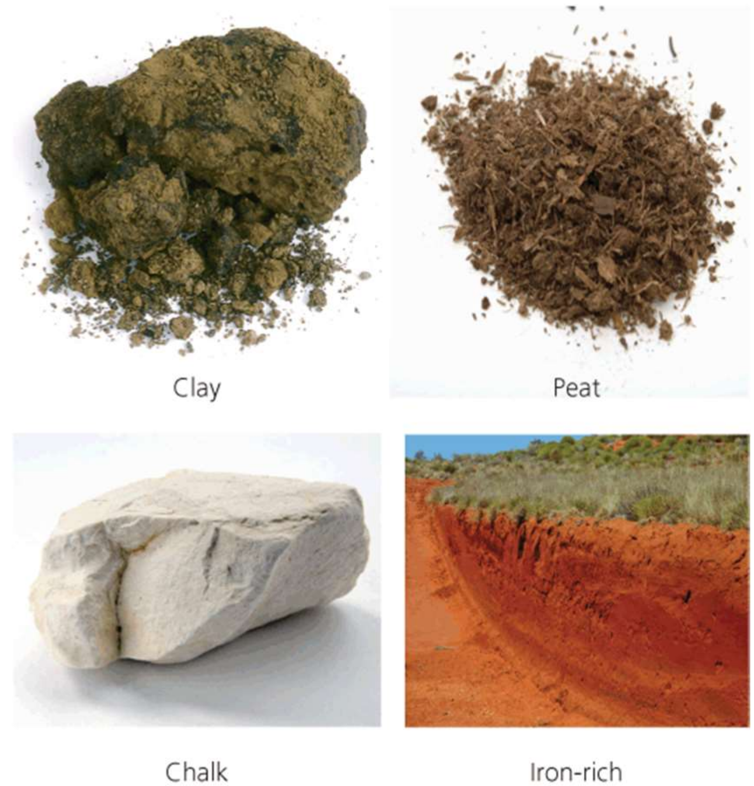


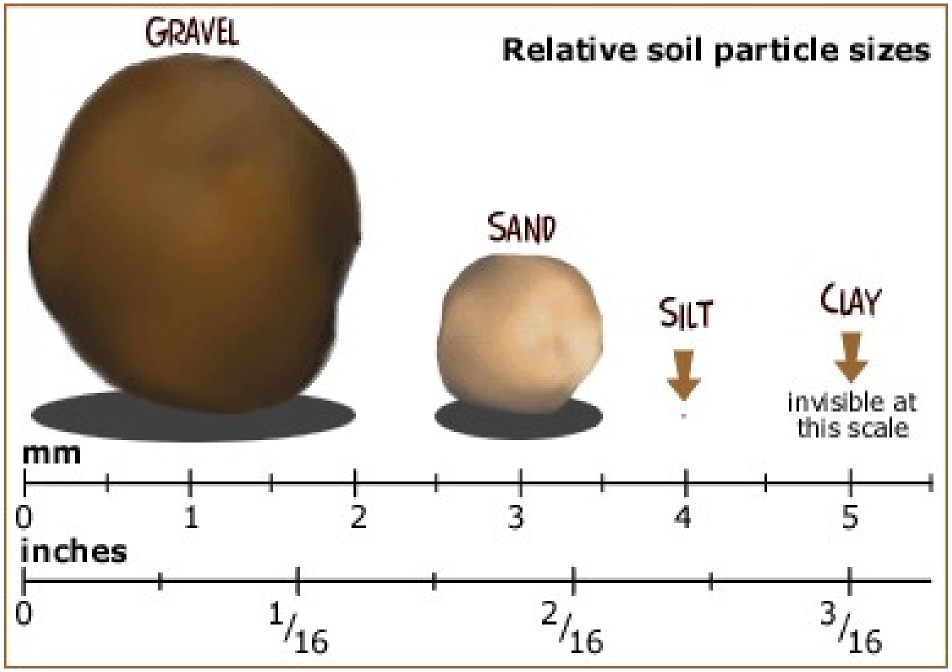
FIGURE 7.4
The colour of soil can vary drastically from one location to another. A soil's composition affects its colour; for instance, soils high in organic matter tend to be dark brown or black, light grey soils are often chalky in composition. Iron-rich soil, such as the one seen here in Central Australia, is often bright red in colour.

SOIL: CLASSIFICATION

- **Soil texture** = the size of particles
  - Clay (smallest), silt, sand (largest)
- **Loam** = soil with an even mixture of the three
  - Influences how easy it is to cultivate and let air and water travel through the soil
- Silty soils with medium-size pores, or loamy soils with mixtures of pore sizes are best for plant growth and crop agriculture

SOIL: CLASSIFICATION

- Classified by composition based on particle size
  - Sand – coarse → high infiltration, percolation
  - Silt – intermediate
  - Clay – finest → less pore volume, hard to penetrate but greater long-term retention



SOIL: CLASSIFICATION

- **Soil structure** = a measure of soil's "clumpiness"
  - Large clumps can discourage plant roots
  - Repeated tilling compacts soil
  - **Plowpan** = a hard layer resulting from repeated plowing that resists water infiltration and root penetration
- **Soil pH** = influences a soil's ability to support plant growth
  - Soils that are too acidic or basic can kill plants

SOIL POLLUTION

1. Direct pollution – dumping, accidental spills (trucks, trains, aeroplanes), leaks, landfills
2. Deposition from atmosphere (especially acid rain)
3. Sediments from water pollution

SOIL DEGRADATION

- Soil contamination or soil pollution is caused by the presence of xenobiotic (human-made) chemicals or other alteration in the natural soil environment.
- Contamination is correlated with the degree of industrialization and intensity of chemical usage
- In North America and Western Europe that the extent of contaminated land is best known
- Developing countries tend to be less tightly regulated

SOIL POLLUTION

- **Soil pollution** is caused by the presence of chemicals or other alteration in the natural soil environment.

- Resulting in a change of the soil quality

- Affect the normal use of the soil or endangering public health and the living environment.

SOIL DEGRADATION: HUMAN INFLUENCE

- Soil pollution starts with the flawed concept of throwing trash on the side of a road and throwing out your dustbin on the road.
- Besides the tons household plastic, industrial dumping of man-made chemicals is also done.
- Not just restricted to developing countries, but highly developed and advanced countries as well.
- Agricultural advancement has also played a part in laying many a green pastures barren.

SOIL DEGRADATION CAUSES

- Mining
- Oil and fuel dumping
- Disposal of coal ash
- Leaching from landfills
- Corrosion of underground storage tanks.
- Application of pesticides and fertilizers.
- Direct discharge of industrial wastes to the soil
- Drainage of contaminated surface water into the soil

SOIL: FIRST EFFECTS OF POLLUTION

- Washed away: might accumulates somewhere
- Evaporate: can be a source of air pollution
- Infiltrate through the unsaturated soil to the groundwater
- DDT: fat soluble, stored in fatty tissues
  - Interferes with calcium metabolism
  - Results in thin egg shells in birds

SOIL DEGRADATION: SEVERITY OF IMPACT

1. Infiltration – how fast pollutant gets into the soil (how fast need to clean up?)

2. Percolation – how far down into the soil does it go? (reach water table?)

3. Retention – how long does it stay?

4. Buffering capacity – (adsorption capacity) – soil becomes toxic only after binding ability/reduction in availability is overcome

SOIL DEGRADATION: TOXICOLOGY

A. **Bulk density** (g/m^3) and porosity

- compact soils have reduced air space = lower infiltration and percolation.

Bulk density is the weight of soil in a given volume.

-Soils with a bulk density higher than 1.6 g/cm3 tend to restrict root growth. Bulk density increases with compaction and tends to increase with depth. Sandy soils are more prone to high bulk density.

SOIL DEGRADATION: TOXICOLOGY

A. …

B. **pH** – sorption to soil is often pH dependent (note: soils are usually good buffers → hard to change pH

1. A polychlorinated biphenyl (PCB) – decreased pH = increased adsorption = decreased toxicity
2. Al, Mn – become more bioavailable as decrease pH = increased toxicity
3. Ammonia – ammonium ion (NH_4^+) converted to ammonia (NH_3) at high pH

SOIL DEGRADATION: TOXICOLOGY

C. Topography

Often determines soil properties and pollution load

1. Ridgetop soils – shallower, better drained than bottomland soil
2. Bottomland soils – greater repository for pollutants
   - collect from ridgetop leaching and what is purposely deposited there

SOIL DEGRADATION: TOXICOLOGY

D. **Organic Matter Content**

1. OM has negative ionic charge that can absorb and retain pollutants
2. High OM soils occur in colder climates and poor soil aeration → both inhibit breakdown of OM

SOIL POLLUTION FACTS

- Soil is a non-renewable resource with more potential to degrade.
- Most countries have very little control over soil pollutant dumping.
- Developed and developing countries have now put a major legal framework and clean-up program in place, to deal with soil pollution.

SOIL POLLUTION: CONTROL

- Use of pesticides and fertilizers should be minimized.
- Cropping techniques should be improved to prevent growth of weeds.
- Special pits should be selected for dumping wastes.
- Controlled grazing and forest management.
- Wind breaks and wind shield in areas exposed to wind erosion (Reduces wind speed, roots hold soil, reduce evaporation and C-seq)
- Afforestation and reforestation.
- **3 Rs: reduce, reuse, recycle**

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SOIL POLLUTION SOLUTIONS

- Reduction of Acid Rain

  Sulfur dioxide emissions can cause acid rain and forest destruction.
- Reduce Waste

  Consider the amount of needlessly generated waste.
- Improve Agriculture.
- Wetland Restoration

  Help restore polluted wetlands.
- Reduction of Human Impact

  Finally, simply reduce your negative impact on the environment.

SOIL POLLUTION SOLUTIONS: INFO NEEDED

- **Kind of material-organic** or inorganic- is the material biodegradable/ dangerous to animals & humans
- **How much material** was added to the soil, will it overload the organisms in the soil
- **C:N ratio of the pollutant material**
- **Nature of soil**: will the soil be able to handle the material before groundwater is contaminated
- **Growing conditions for the soil organisms:** - is it too cold, too wet etc.
- **How long the material has been on site:** is there evidence of environmental problems, is it undergoing decomposition.
- **Immediate danger to people & environment:** Urgency of the situation.

SOIL DEGRADATION: REMEDIATION

A. **Liming** or acid addition – adjust/balance pH

B. Soil **burning**

- very costly, not usually done
- way to dispose of dioxin → burn at 1000° C. (reason why Agent Orange burned at sea)

C. Soil **removal**

- common method, but really just moving pollutants around
- Now just used for special cases (e.g. Radon→ PA, NJ, Mn)

SOIL DEGRADATION: REMEDIATION

D. Bioremediation

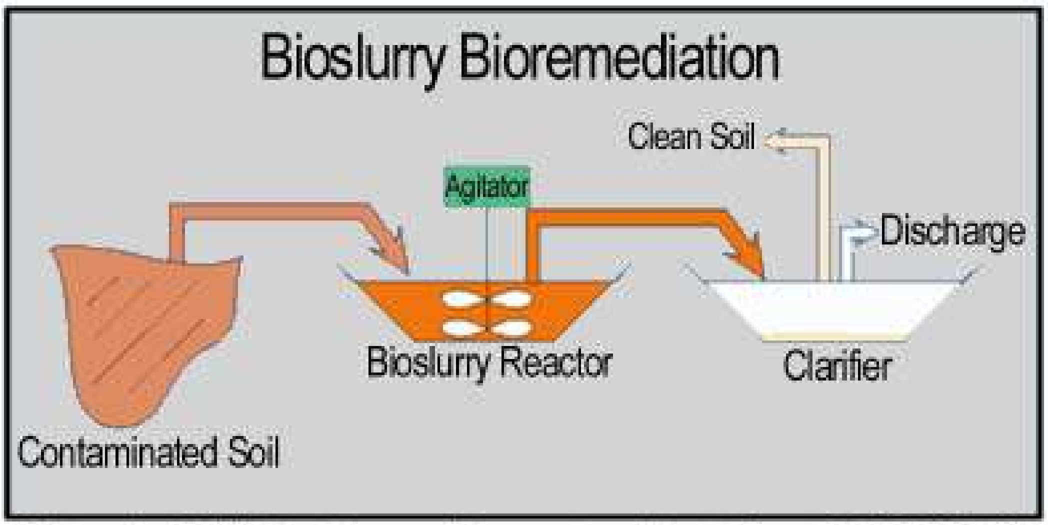
- toxin-eating microbes → good possibility for GMO's?

E. Containment

- put up fence and signs to keep away or DIE!

F. Pump and Treat

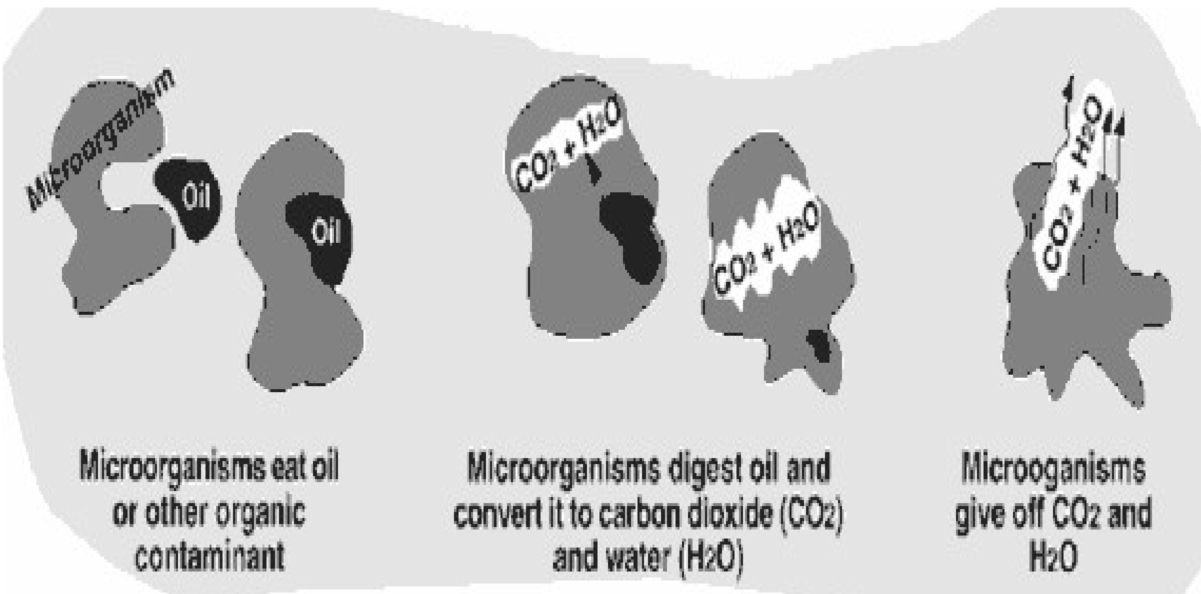
- Contaminated groundwater from contaminated soil, may treat chemically or burn



Schematic of a bioslurry bioremediation system. Adapted from the U.S. EPA (8).

SOIL DEGRADATION: BIOREMEDIATION

- The use of naturally occuring microorganisms such as bacteria, fungi & plants to break down or degrade toxic chemical compounds that have accumulated in the environment
- It is a method that treats the soils and renders them non-hazardous, thus eliminating any future liability that may result from landfill problems or violations.



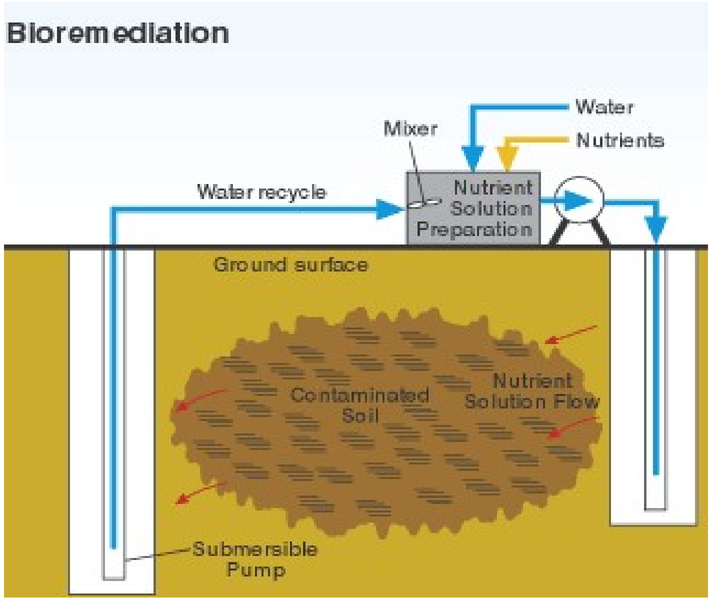
FACTORS AFFECTING: BR

- Microbial factors
- Temperature favorable for organisms
- Availability of water (Moisture content)
- Availability of nutrients (N, P, K)
- C: N ratio of the contaminant material< 30:1
- pH
- Availability of Oxygen in sufficient quantity in soil.

- *In situ* Bioremediation : The treatment in place without excavation of contaminated soils or sediments.
- *Ex situ* bioremediation: requires pumping of the groundwater or excavation of contaminated soil prior to remediation treatments.

TYPES OF IN-SITU BR

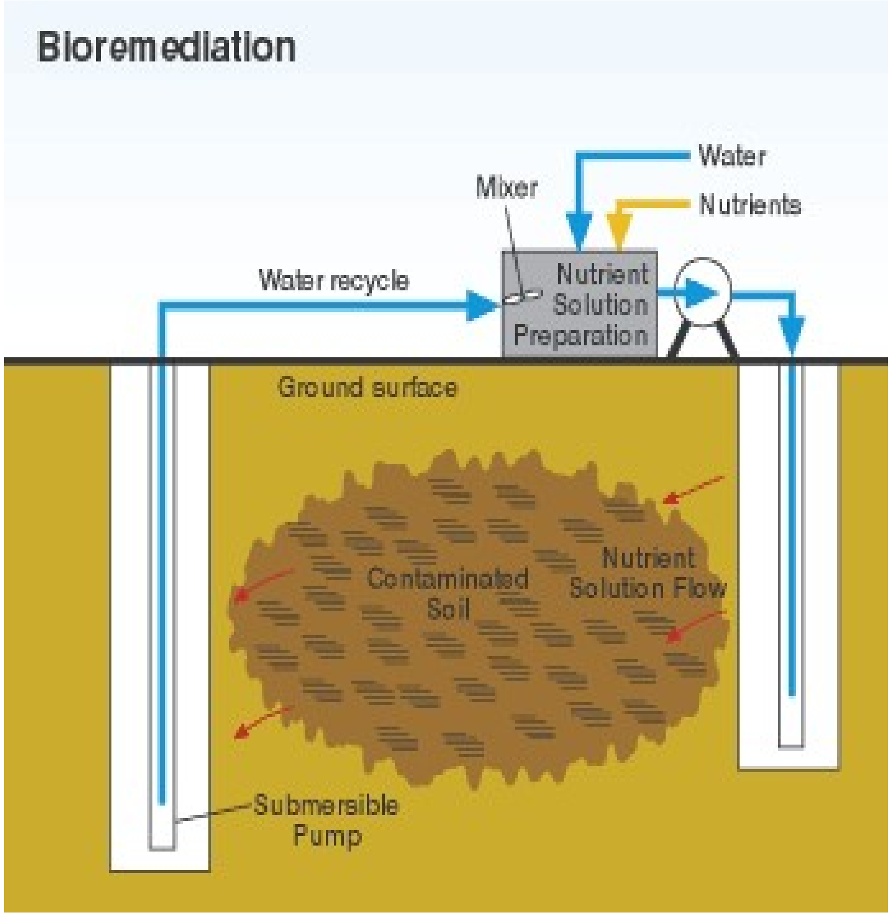
- **Biostimulation:** To stimulate the activity of microorganisms by adding nutrients and electron acceptors (*e.g.* O_2)
- **Bioventing:** Injecting air through soil to stimulate microbe growth in unsaturated zone
- **Biosparging:** Injection of air/nutrients into unsaturated and saturated zones
- **Bioaugmentation:** inoculation of soil with microbes or adding exogenous microbes to the subsurface



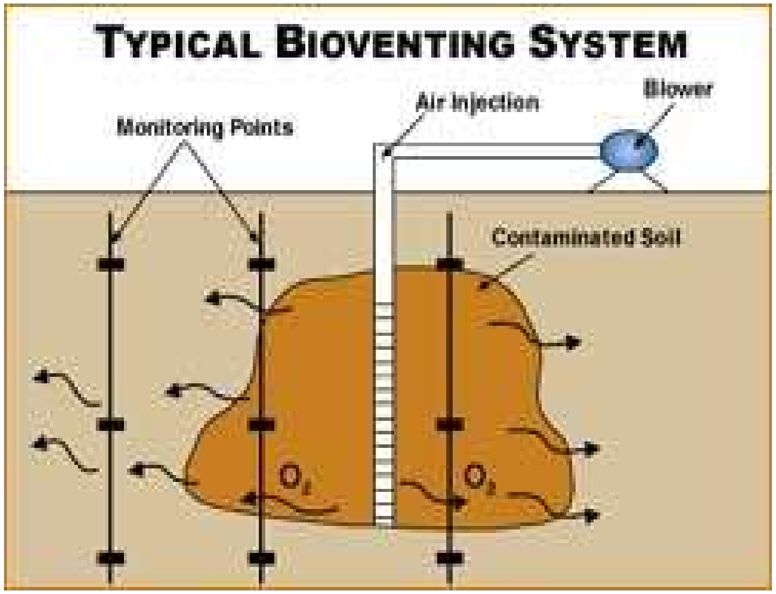
- **Good for large volumes**
- **Slower**
- **Doesn't work well in clays or highly layered subsurfaces**

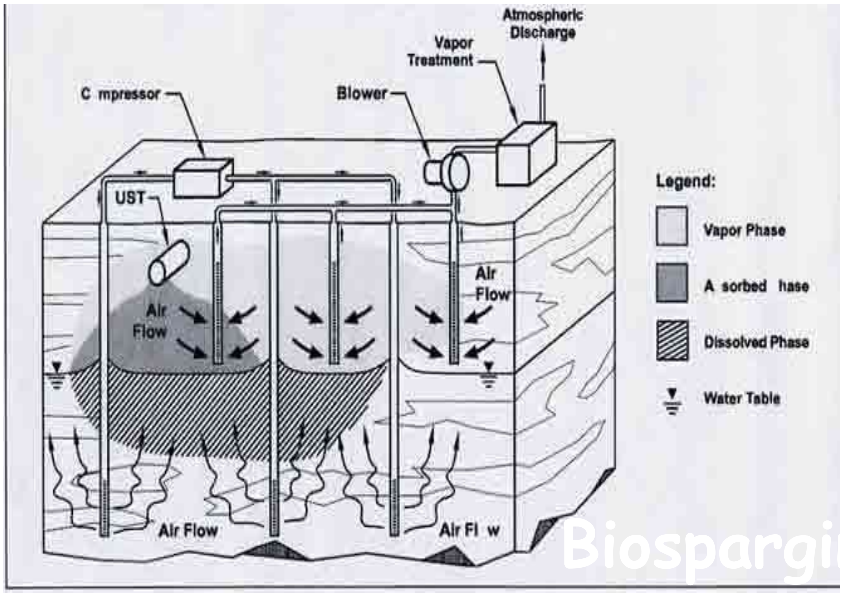
Less expensive

- Creates less dust
- Less possibility of contaminant release into environment



BIO-STIMULATION





Ex-situ -Bioremediation

- *Slurry-phase*-Soil combined with water/additives in tank, microorganisms, nutrients, oxygen added

- *Solid-phase*
  - Land-farming: soil put on pad, leachate collected
  - Soil biopiles: soil heaped, air added
  - Composting: biodegradable waste mixed with bulking agent
  - Land Applied –waste added directly to soil which is later planted to a crop.

- Easier to control
- Used to treat wider range of contaminants and soil types
- Costly
- Faster

Advantages of Using Bioremediation Processes Compared With Other Remediation Technologies

(1) Biologically-based remediation detoxifies hazardous substances instead of merely transferring contaminants from on environmental medium to another;

(2) Generally less disruptive to the environment than excavation-based processes; and

(3) The cost of treating a hazardous waste site using bioremediation technologies can be **considerably lower** than that for conventional treatment methods: vacuuming, absorbing, burning, dispersing, or moving the material .

AGRO/
VEGETATION /
FORESTRY

SOIL DEGRADATION

SOIL DEGRADATION

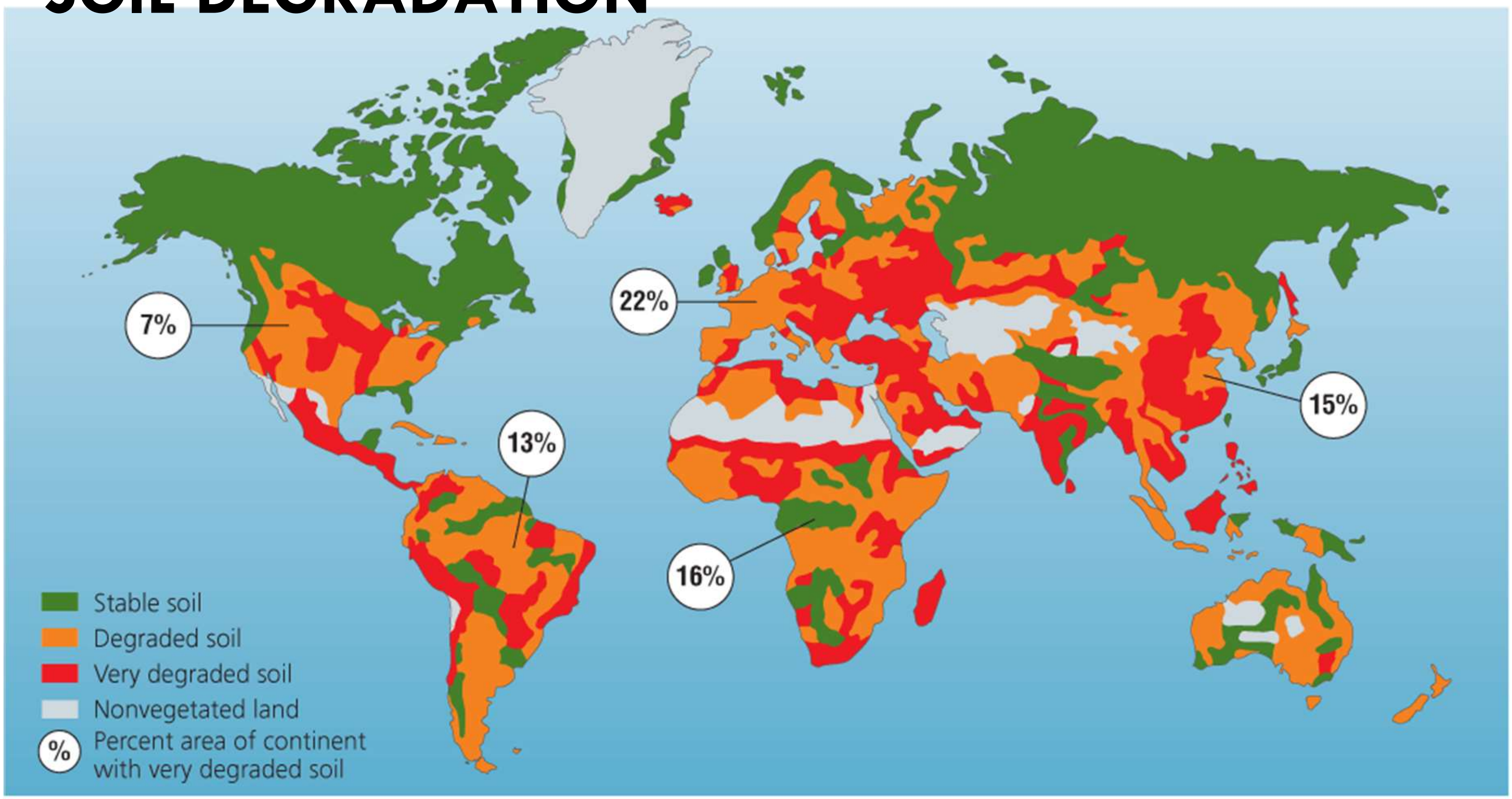


FIGURE 7.9 Soils are becoming degraded in many areas worldwide. Europe currently has a higher proportion of degraded land than other continents because of its long history of intensive agriculture, but degradation is rising quickly in developing countries in Africa and Asia. *Source: Data from United Nations Environment Programme (UNEP), 2002.* Global Environmental Outlook 3. *London: UNEP and Earthscan Publ.*

SOIL DEGRADATION

- Soil degradation results from deforestation, agriculture and overgrazing
- Over the past 50 years, soil degradation has reduced global grain production by 13%

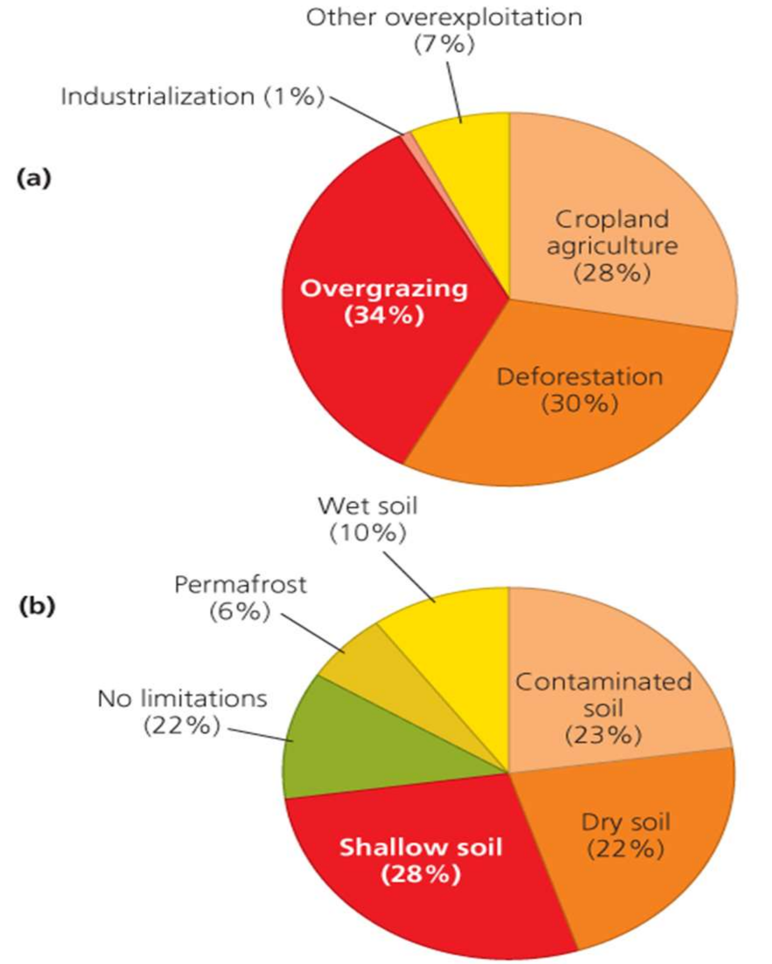


FIGURE 7.10
(a) Most of the world's soil degradation results from cropland agriculture, over-grazing by livestock, and deforestation. Data based on information from UNEP. **(b)** Various factors limit the agricultural productivity of soil, as shown in this diagram based on information from the United Nations Food and Agriculture Organization.

SOIL DEGRADATION: CAUSES

- Soil erosion/degradation is the loss of top soil erodes fertility of soil & reduces its water-holding capacity.
- Excessive farming, construction, overgrazing, burning of grass cover and deforestation
- Excess salts and water (Salinization)
- Excessive use of fertilizers & pesticides
- Solid waste

SOIL DEGRADATION: REGIONAL DIFFERENCES

- Rainforests have high primary productivity, but the nutrients are in plants, not the soil. If the forests are removed, the soils dry out and cannot readily be regenerated.
- **Swidden agriculture** = cultivation of a plot for a few years and then letting it regrow into forest

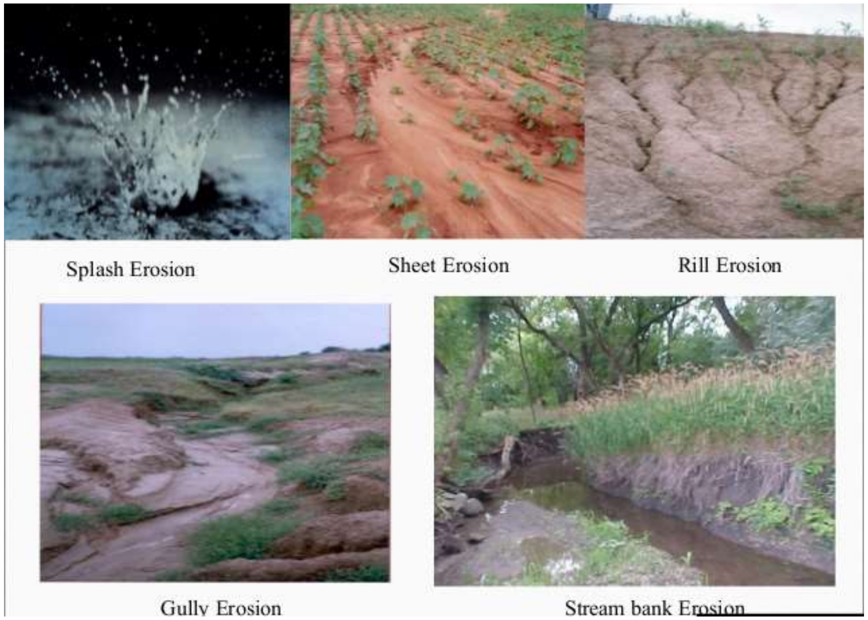
- Temperate grasslands have lower rainfall and less nutrient leaching

Erosion can degrade ecosystems and agriculture

- **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 occurs faster than new soil is formed
- Erosion increases through: overcultivating fields, overgrazing rangelands, and clearing forested areas

Soil erodes by several mechanisms

- Wind (aeolian) erosion
- Water erosion (splash, sheet, rill, gully)
  - Rill erosion moves the most topsoil, followed by sheet and splash erosion
- Predicting losses by erosion:
  - Universal Soil Loss Equation (USLE)
  - Wind Erosion Prediction Equation



Soil erosion is widespread

- Humans are the primary cause of erosion
- 19 billion hectares of croplands worldwide suffer from erosion
- Kazakhstan lost tends of millions of hectares to wind erosion
- Soil degradation over the next 40 years in Africa could reduce crop yields by half

Desertification reduces productivity of arid lands

- **Desertification**
  - A loss of more than 10% productivity from erosion, soil compaction, forest removal, overgrazing, salinization, climate change, depletion of water sources
  - A type of land degradation
  - Affects 1/3 of the planet's land area
  - Most prone areas are arid and semiarid lands
  - Climate change could result in displacement of 50 million people in 10 years

The Dust Bowl, also known as the Dirty Thirties, was a period of severe dust storms that greatly damaged the ecology and agriculture of the American and Canadian prairies during the 1930s; severe drought and a failure to apply dryland farming methods to prevent wind erosion (the Aeolian processes) caused the phenomenon

A black blizzard rolls through Stratford, Texas; 1935.

The Dust Bowl was a monumental event in North America

FIGURE 7.14
(a) Desertification occurs when formerly productive land turns into desert, as shown here in this photo from Mauritania, Africa. **(b)** Canada is not exempt from the impacts of wind erosion, as shown in this photo from the Dust Bowl of the 1930s.

(a)

(b)

PROTECTING SOIL

Erosion-control practices protect and restore plant cover

- Crop rotation
- Contour farming
- Intercropping and agroforestry
- Terracing
- Shelterbelts
- Reduced tillage

(a) Crop rotation

(b) Intercropping

- **Crop Rotation** = alternating the crops grown field from one season or year to the next
  - Cover crops protect soil

- **Intercropping** = planting different types of crops in alternating bands or other spatially mixed arrangements to increase ground cover


(c) Contour farming


(d) Terracing

- **Contour Farming** = plowing furrows sideways across a hillside, perpendicular to its slope, to prevent rills and gullies

- **Terracing** = level platforms are cut into steep hillsides, forming a "staircase" to contain water

(e) Shelterbelts

(f) No-till farming

- **Shelterbelts or Windbreaks** = rows of tall, perennial plants are planted along the edges of fields to slow the wind
  - **Alley cropping** = shelterbelts + intercropping
- **Reduced Tillage** = furrows are cut in the soil, a seed is dropped in and the furrow is closed

Irrigation can cause long-term soil problems

- **Irrigation** = Artificially providing water to support agriculture
- **Waterlogging** = over-irrigated soils which suffocates roots
- **Salinization** = the buildup of salts in surface soil layers
  - Salinization inhibits production of 20% of all irrigated cropland, costing more than $11 billion/year

Irrigation can cause long-term soil problems

- Remedies for correcting salinization once it has occurred:
  - Choose crops appropriate for the area
  - Irrigate with low-salt water
  - Irrigate efficiently
    - **Drip irrigation** targets water directly to plants

Other chemicals also contribute to soil contamination

- **Fertilizer** = substances that contain essential nutrients but over-application can damage soils
- **Inorganic fertilizers** = mined or synthetically manufactured mineral supplements
- **Organic fertilizers** = the remains or wastes of organisms
  - manure, crop residues, fresh vegetation
  - **Compost** = produced when decomposers break down organic matter
  - Not perfect when it gets into the water system

Other chemicals also contribute to soil contamination

- Nitrogen and phosphorous runoff from farms and other sources can lead to algal blooms
- Nitrates can leach through soil and contaminate groundwater
- Pesticides are another source of soil contamination
- Industrial activity contaminates soil through inappropriate disposal of wastes and improper storage

Grazing practices can contribute to soil degradation

Overgrazing is largely responsible for the permanent drying out of parts of the Mediterranean – e.g. Greece and Syria

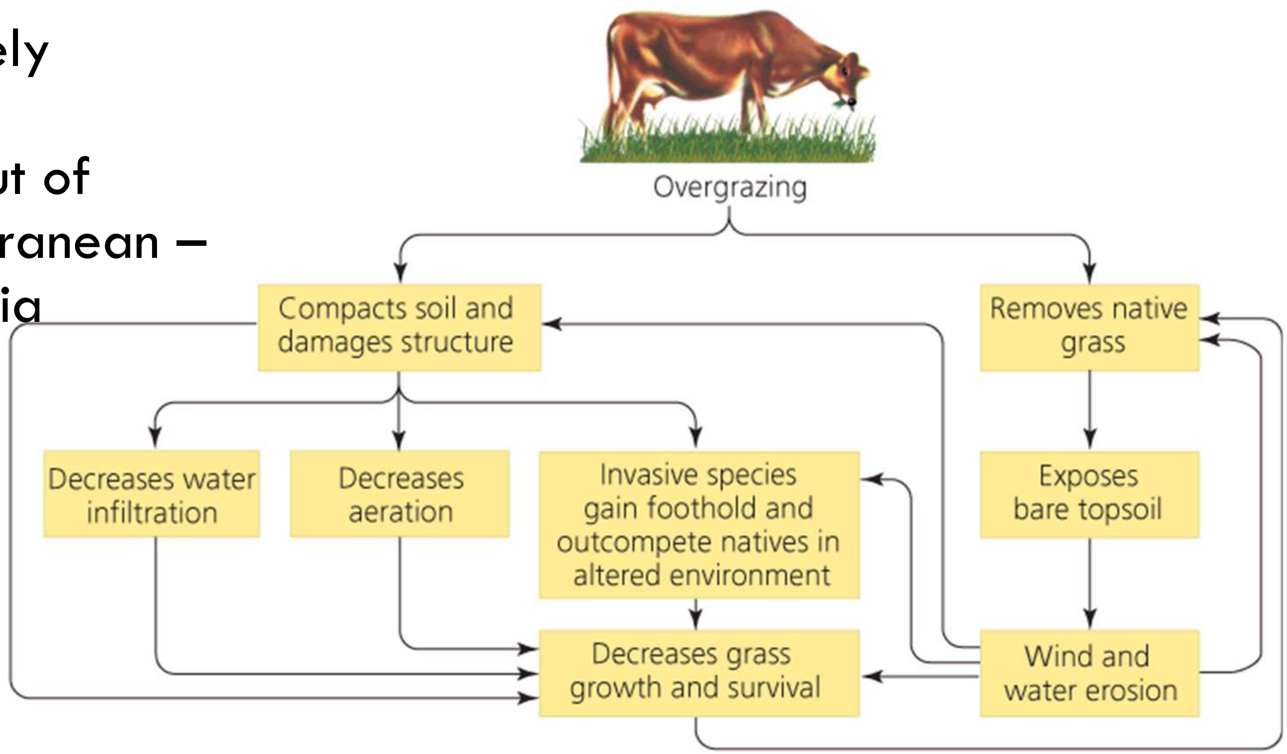


FIGURE 7.18
When grazing by livestock exceeds the carrying capacity of rangelands and their soil, over-grazing can set in motion a series of consequences and positive feedback loops that degrade soils and grassland ecosystems.

SUMMARY

- The preservation of arable soil is crucial for the maintenance of global food security
- Programs worldwide have been successful in reducing topsoil erosion
- However, soil is still being degraded at a rate that threatens the sustainability of the resource
- The role of soil as a reservoir in biogeochemical cycling is also of increasing interest to scientists

QUESTIONS

- What is the importance of soil in our environment?
- What is soil pollution and how soil becomes polluted?
- What are the factors that determine the severity of soil degradation?
- What are the reasons for soil erosion and what is the impact of top soil erosion on agriculture?
- How can we control soil pollution? Explain a method for this.
- What is bioremediation?
- What is the connection between soil health and global food security?