Soil microbiology

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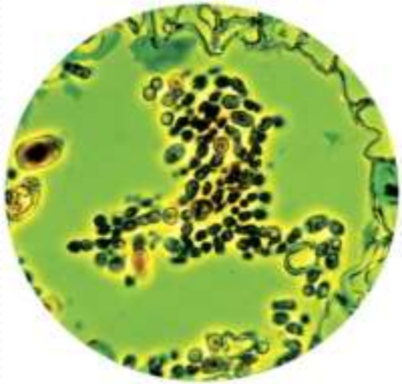
Soil Microbiology

- It is branch of science dealing with study of soil microorganisms and their activities in the soil, their functions, and how they affect soil properties
- form a very small fraction of soil mass (volume of less than 1%)
- In the upper layer of soil (top soil up to 10-30 cm depth i.e. Horizon A), the microbial population is very high which decreases with depth of soil



Importance of microorganisms

- affect the structure and fertility of different soils.
- contribute to nutrient availability in soil(OM decomposition, humus formation, N-fixation, seed germination)
- manage soil stability by different biochemical processes
- Degrade pesticides and chemicals in soil
- Contribute the growth and success of the plants and overall ecosystem of a soil environment.

Types

- Types of microorganisms
  - Bacteria
  - Actinomycetes
  - Fungi
  - Algae
  - protozoa

Bacteria

- smallest organisms in the soil
- Prokaryotic(simple cell structure with no internal organelles)
- most abundant microorganisms in the soil
- Serve many important purposes, one of those being nitrogen fixation among other biochemical processes.

Biochemical processes of bacteria

- Nitrogen fixation(*Nitrobacter* sp.)
- Degradation (Sulphur degradation, hydrocarbon degradation etc)
- Used for remediation (*Pseudomonas* sp. etc)

Actinomycetes

- similar to both bacteria and fungi
- have characteristics linking them to both groups.
- missing evolutionary link between bacteria and fungi
- Produce antibiotics

Characteristics

- **Similarities to bacteria**
  - Prokaryotic
  - sensitive to anti-bacterials
  - resemble bacteria in size, shape and gram-staining properties.
- **Similarities to fungi**
  - shape and branching properties, spore formation
  - Reproduction mechanism

Fungi

- abundant after bacteria
- food sources for other organisms
- beneficial symbiotic relationships with plants or other organisms
- reduce crop residues
- biochemically process nutrients to improve the soil
- split into different species based on size, shape and color of their spores, which are used to reproduce.

Factors effecting growth of fungi

- quality as well as quantity of OM in the soil has a direct correlation to the growth of fungi
- fungi abundant in in acidic areas compared to bacteria
- Fungi also grows well in dry, arid soils (aerobic, or dependent on oxygen)

Algae

- Algae can make its own nutrients through a process known as photosynthesis
- distributed evenly wherever sunlight and moderate moisture is available
  - do not have to be on the soil surface or directly exposed to sun rays
  - can live below the soil surface as long as the algae has uniform temperature and moisture conditions.

Algae in soil

- Possess the character of symbiotic nitrogen fixation in association with other organisms like fungi, mosses, and liverworts
- association fix nitrogen symbiotically in rice fields.
- Plays important role in the maintenance of soil fertility especially in tropical soils
- Add organic matter to soil when die and thus increase the amount of organic carbon in soil
- Most of soil algae (especially BGA) act as cementing agent in binding soil particles and thereby reduce/prevent soil erosion

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- Mucilage secreted by the BGA is hygroscopic in nature and thus helps in increasing water retention capacity of soil for longer time/period
- Soil algae through the process of photosynthesis liberate large quantity of oxygen in the soil environment and thus facilitate the aeration in submerged soils or oxygenate the soil environment
- help in checking the loss of nitrates through leaching and drainage especially in un-cropped soils
- They help in weathering of rocks and building up of soil structure

Protozoa

- eukaryotic organisms
- Sexual reproduction
- Biological control agent
  - Maintain equilibrium in soil microbes
- Protozoa can be split up into three categories: flagellates, amoebae, and ciliates

Types of flagellates

- smallest members of the protozoa group, and can be divided further based on whether
  - Non chlorophyll-containing flagellates found mostly in soil and flagellates that contain chlorophyll typically occur in aquatic conditions.
  - distinguished by their flagella

Amoeba

- larger than flagellates and move in a different way
- slug-like properties and pseudopodia
- does not have permanent appendages

Ciliates

- largest of the protozoa group
- move by means of short, numerous cilia

Soil microbes and soil structure

- Soil structure dependent on stable aggregates of soil particles
- Soil organisms play important role in soil aggregation
- Constituents of soil are organic matter, polysaccharides, lignins and gums synthesized by soil microbes plays important role in cementing of soil particles
- cells and mycelial strands of fungi and actinomycetes play important role in soil aggregation

Cont’d

- Different soil microorganisms, having soil binding properties are graded in the order as:

  fungi > actinomycetes > gum producing bacteria > yeasts

  Examples :

  - Fungi like Rhizopus, Mucor, Chaetomium,Fusarium, Cladasporium, Rhizoctonia, Aspergillus, Trichoderma
  - Bacteria like Azofobacler, Rhizobium Bacillus and Xanthomonas.

Soil microbes and plant growth

- best medium for plant growth.
- convert complex organic nutrients into simpler inorganic forms which are readily absorbed by the plant for growth.
- produce variety of substances like IAA, gibberellins, antibiotics etc. which directly or indirectly promote the plant growth.

Biological nitrogen fixation

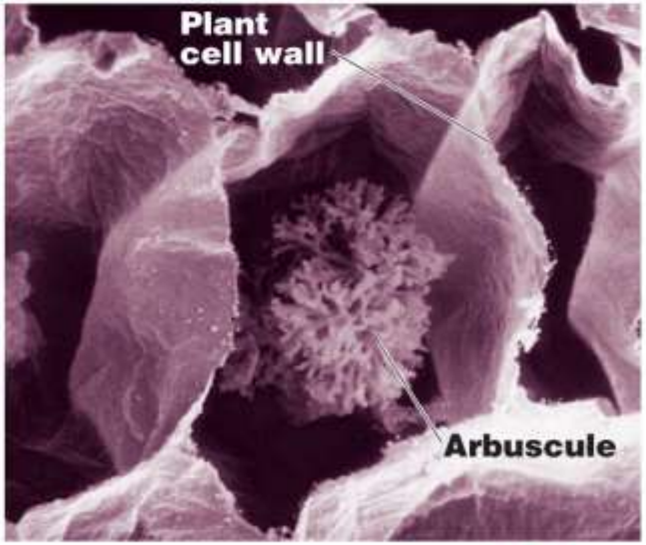
- microorganisms fix 60% nitrogen for requirement of plants
- Two groups of microorganisms are involved in the process of BNF
- Non-symbiotic (free living):
  - aerobic heterotrophs (*Azotobacter, Pseudomonas, Achromobacter*)
  - aerobic autotrophs (*Nostoc, Anabena, Calothrix,* BGA)
  - anaerobic heterotrophs (*Clostridium, Kelbsiella. Desulfovibrio*) o
  - anaerobic Autotrophs (*Chlorobium, Chromnatium, Rhodospirillum, Meihanobacterium* etc)

Cont'd

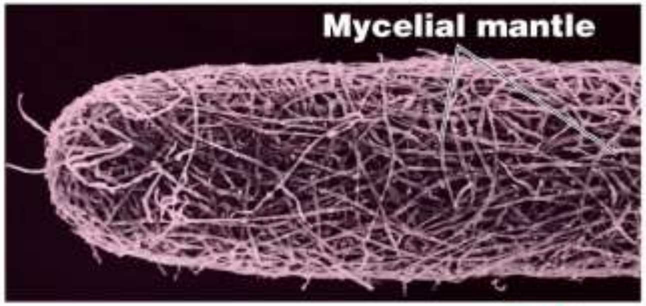
- Symbiotic (Associative): *Rhizobium*, *Bratfyrhizobium* in legumes
- (aerobic): *Azospirillum* (grasses), *Actinomycetes*

Mycorrhizae

- Fungi living in close association with plant roots
- Extend surface area of roots



(a) Endomycorrhiza (vesicular-arbuscular mycorrhiza). A fully developed arbuscule of an endomycorrhiza in a plant cell. (The term *arbuscule* means "little bush.") As the arbuscule decomposes, it releases nutrients for the plant.



(b) Ectomycorrhiza. The mycelial mantle of a typical ectomycorrhizal fungus surrounding a *Eucalyptus* tree root.

Figure 27.1

Commercial use of mycorrhizae

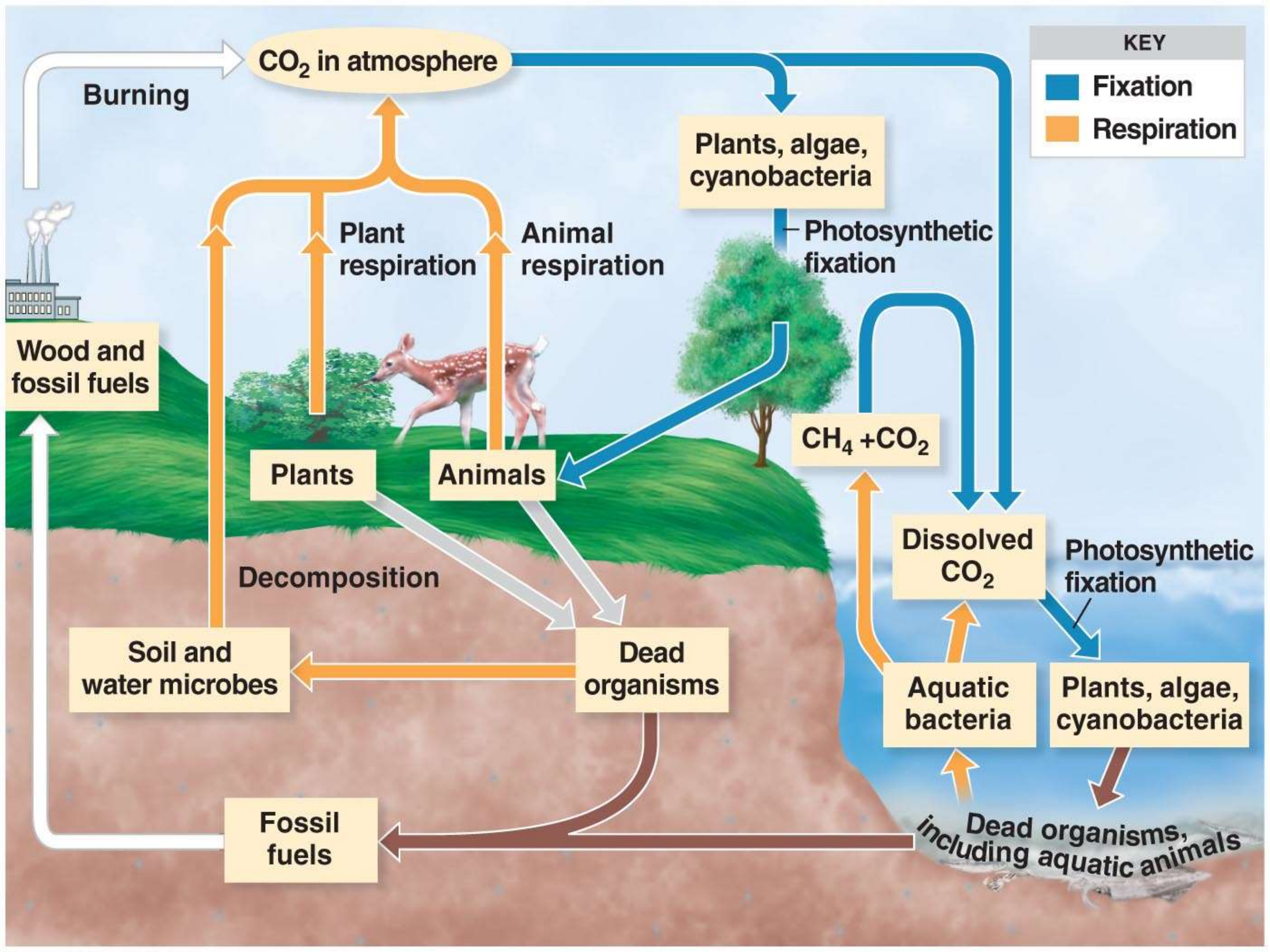
(a) Infection by mycorrhizae strongly influences the growth of many plants. Shown is the relative growth of two pine seedlings: the seedling on the left was inoculated with mycorrhizae; the seedling on the right was not.

(b) Truffles. Of the three truffles shown, one has been sliced to show the interior.

Biogeochemical Cycles and microbes

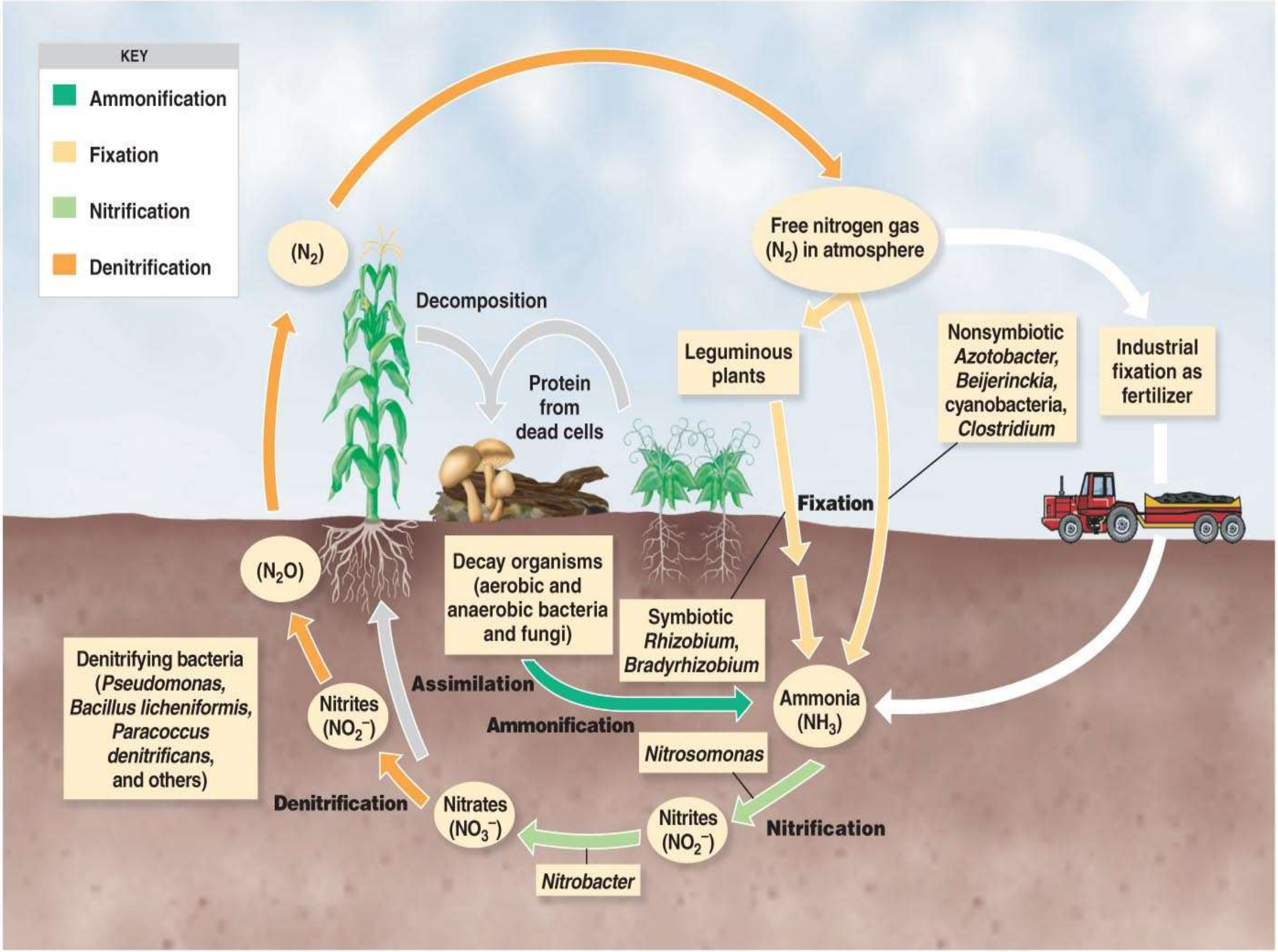
- **Biogeochemical cycles:** Recycling (oxidation and reduction) of chemical elements
- **carbon cycle** (role of microoganisms in this cycle)
- **nitrogen cycle**(role of microorganisms in this cycle)
  - *ammonification, nitrification, denitrification,* and *nitrogen fixation*.
- **sulfur cycle** (role of microorganisms in this cycle)

Carbon cycle



CO_2 in atmosphere
Burning
KEY
Fixation
Respiration
Plants, algae, cyanobacteria
Photosynthetic fixation
Plant respiration
Animal respiration
Wood and fossil fuels
Plants
Animals
$CH_4 + CO_2$
Dissolved CO_2
Photosynthetic fixation
Decomposition
Soil and water microbes
Dead organisms
Aquatic bacteria
Plants, algae, cyanobacteria
Fossil fuels
Dead organisms, including aquatic animals

Nitrogen cycle


KEY
Ammonification
Fixation
Nitrification
Denitrification
(N_2)
Free nitrogen gas (N_2) in atmosphere
Decomposition
Protein from dead cells
Leguminous plants
Nonsymbiotic *Azotobacter*, *Beijerinckia*, cyanobacteria, *Clostridium*
Industrial fixation as fertilizer
Fixation
(N_2O)
Decay organisms (aerobic and anaerobic bacteria and fungi)
Symbiotic *Rhizobium*, *Bradyrhizobium*
Denitrifying bacteria (*Pseudomonas*, *Bacillus licheniformis*, *Paracoccus denitrificans*, and others)
Assimilation
Nitrites (NO_2^-)
Ammonification
Ammonia (NH_3)
Nitrosomonas
Denitrification
Nitrates (NO_3^-)
Nitrites (NO_2^-)
Nitrification
Nitrobacter

The Nitrogen Cycle

$$\text{Proteins and waste products} \xrightarrow{\text{Microbial decomposition}} \text{Amino acids}$$

$$\text{Amino acids } (-NH_2) \xrightarrow{\text{Microbial ammonification}} \text{Ammonia } (NH_3)$$

$$\text{Ammonium ion } (NH_4^+) \xrightarrow{\textit{Nitrosomonas}} \text{Nitrite ion } (NO_2^-)$$

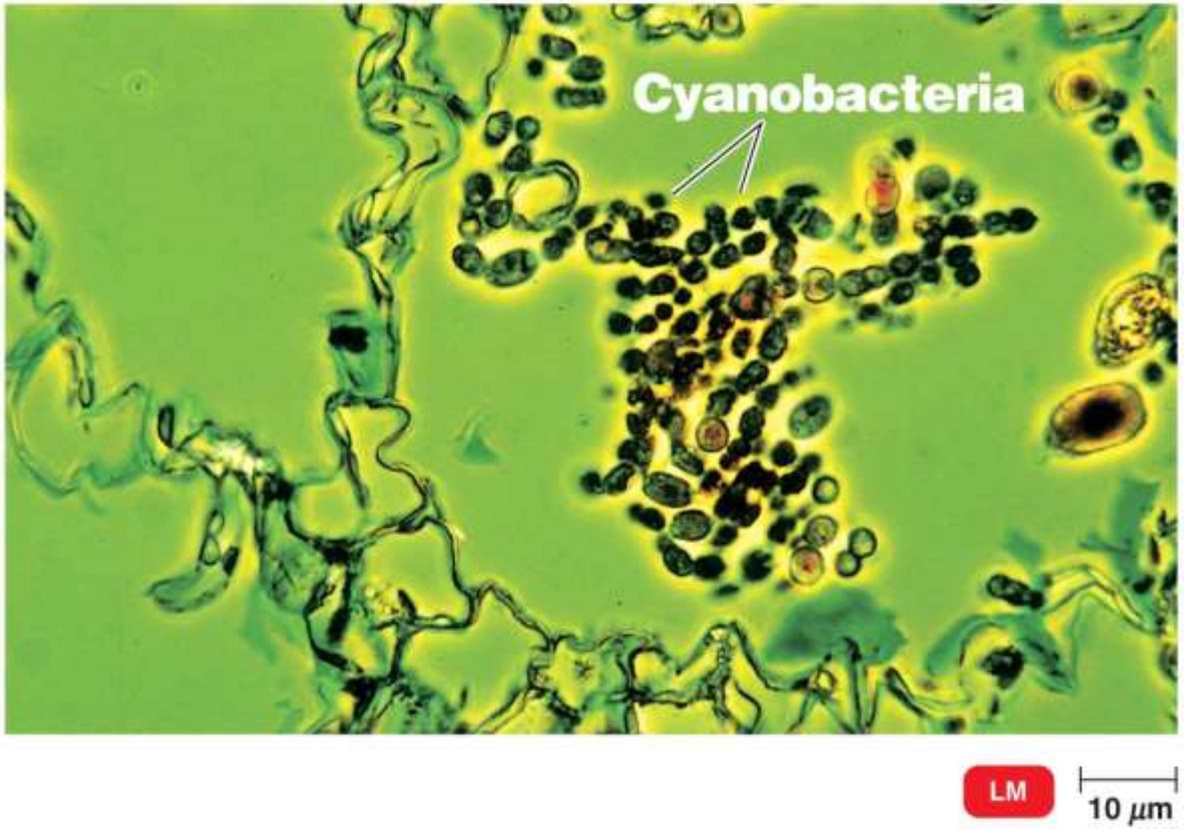
$$\text{Nitrite ion } (NO_2^-) \xrightarrow{\textit{Nitrobacter}} \text{Nitrate ion } (NO_3^-)$$

$$\text{Nitrate ion } (NO_3^-) \xrightarrow{\textit{Pseudomonas}} N_2$$

$$N_2 \xrightarrow{\text{Nitrogen fixation}} \text{Ammonia } (NH_3)$$

Nitrogen Fixation

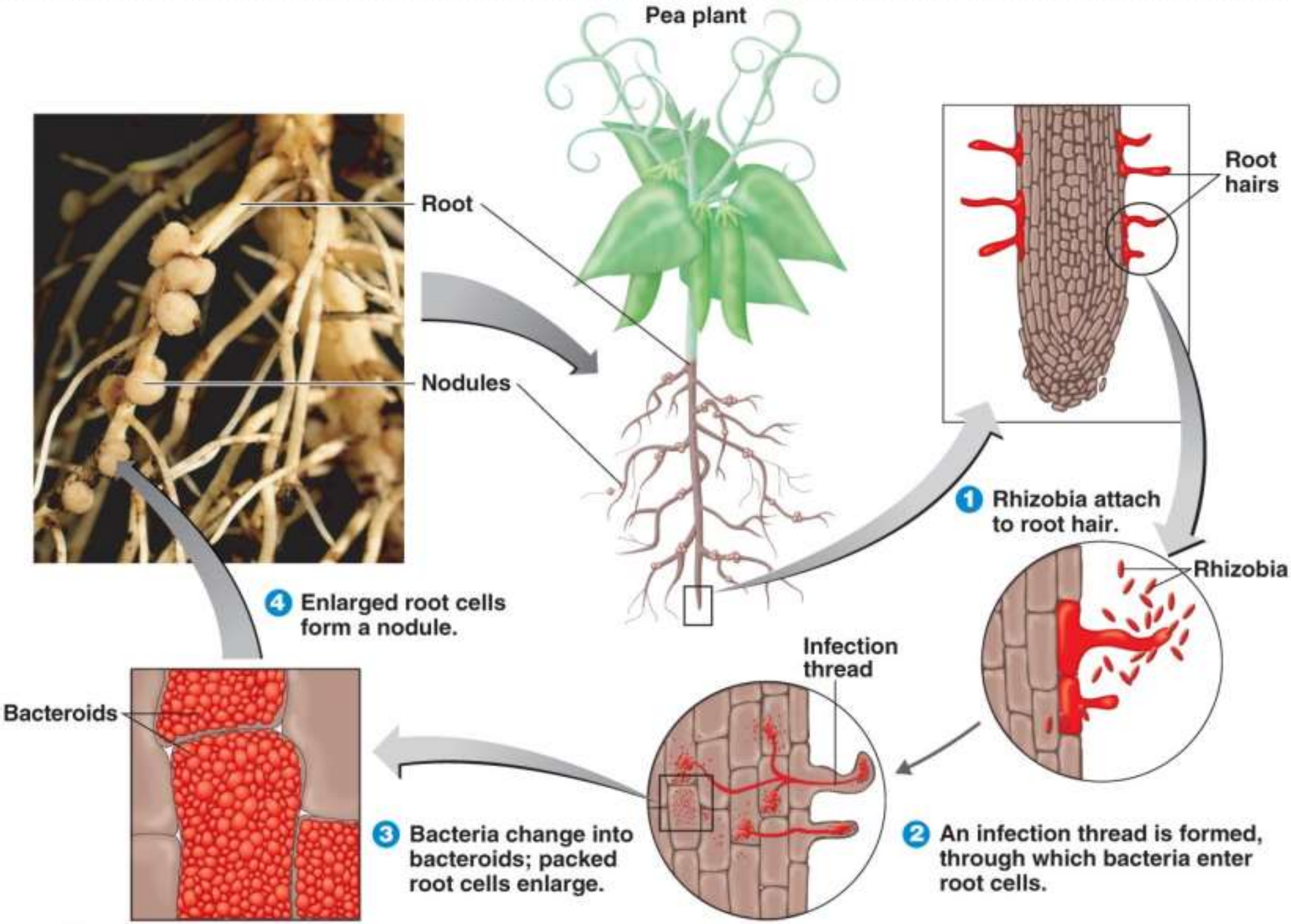
- In rhizosphere
  - *Azotobacter*
  - *Beijerinckia*
  - *Clostridium pasteurianum*
  - *Cyanobacteria*: **heterocysts**



Nitrogen Fixation

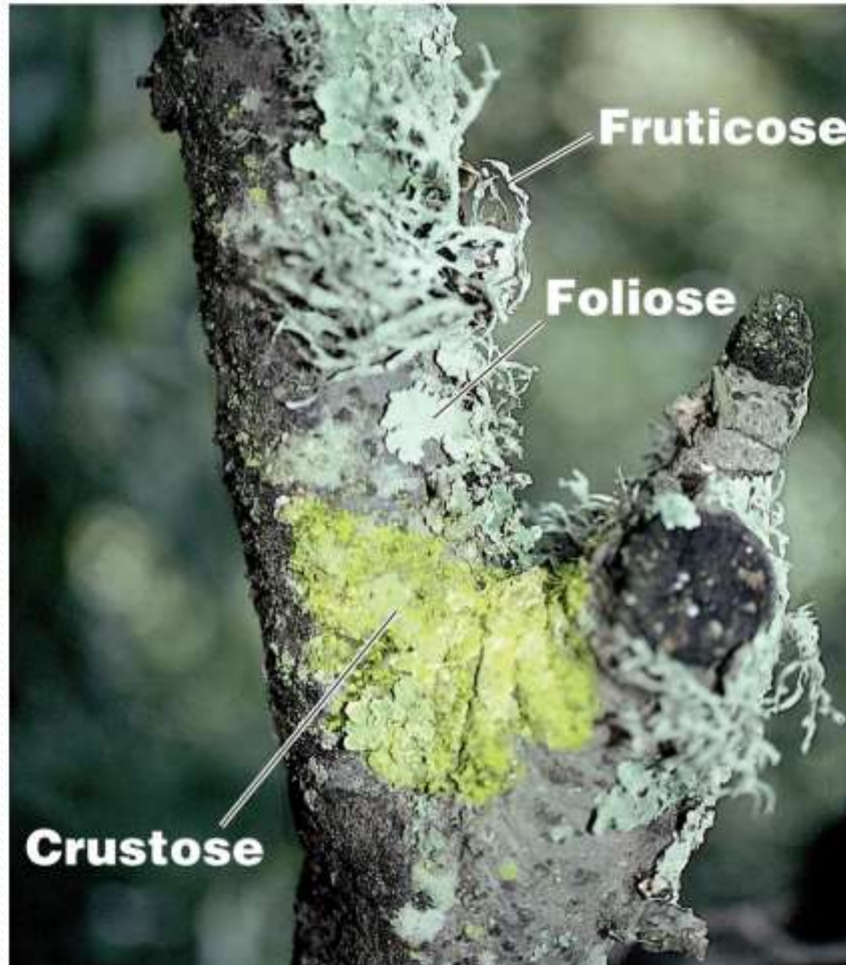
- In **root nodules**
  - *Rhizobium*
  - *Bradyrhizobium*
  - *Frankia*

The Formation of a Root Nodule



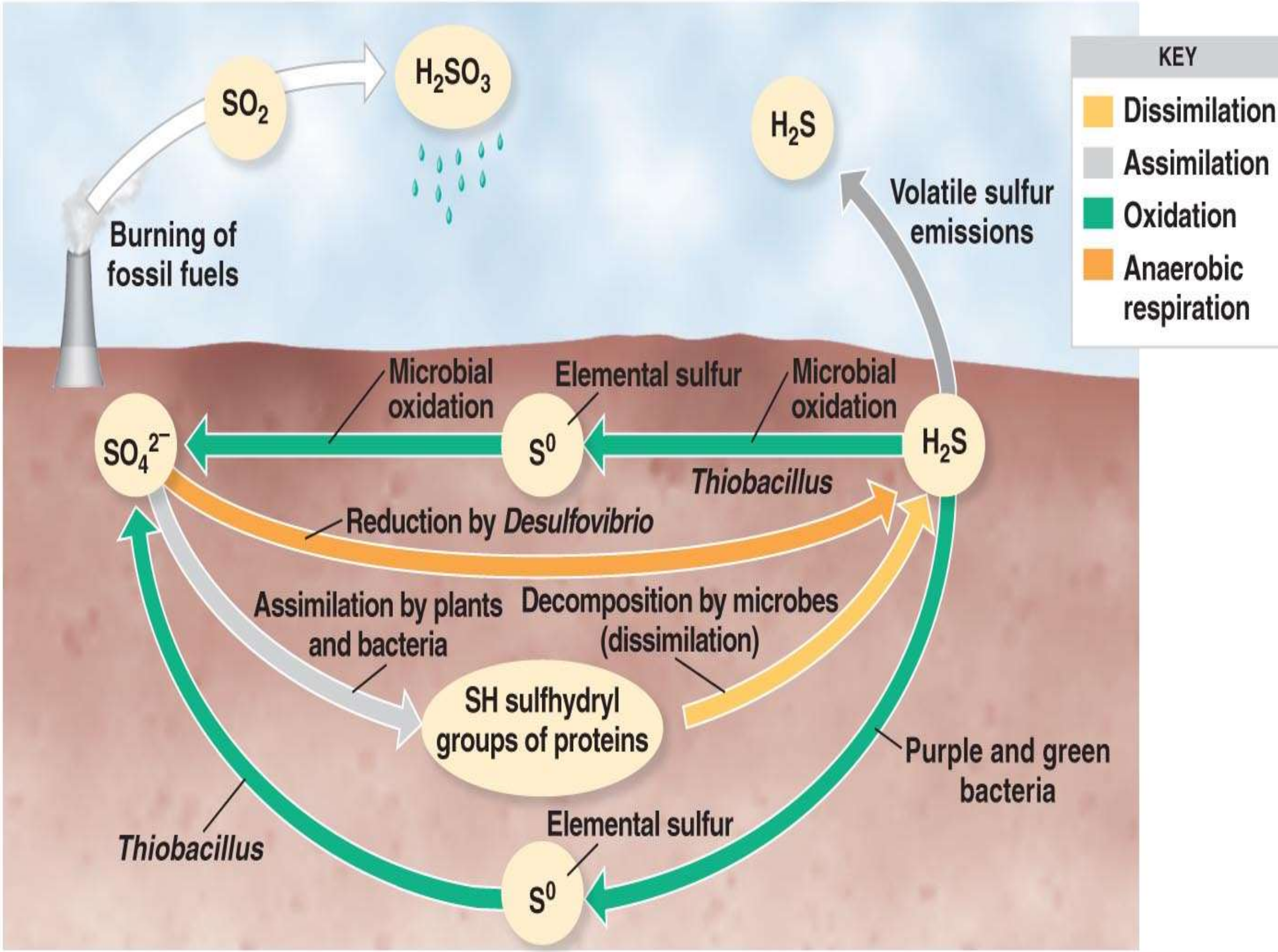
Nitrogen Fixation

- In **lichens**
  - *Cyanobacteria*



(a) Three types of lichens
2 cm

The Sulfur Cycle



SO_2
H_2SO_3
H_2S
KEY
Dissimilation
Assimilation
Oxidation
Anaerobic respiration
Burning of fossil fuels
Volatile sulfur emissions
Microbial oxidation
Elemental sulfur
Microbial oxidation
SO_4^{2-}
S^0
H_2S
Thiobacillus
Reduction by *Desulfovibrio*
Assimilation by plants and bacteria
Decomposition by microbes (dissimilation)
SH sulfhydryl groups of proteins
Purple and green bacteria
Elemental sulfur
Thiobacillus
S^0

The Sulfur Cycle

Proteins and waste products $\xrightarrow{\text{Microbial decomposition}}$ Amino acids

Amino acids (–SH) $\xrightarrow{\text{Microbial dissimilation}}$ H_2S

H_2S $\xrightarrow{\textit{Thiobacillus}}$ SO_4^{2-} (for energy)

SO_4^{2-} $\xrightarrow{\text{Microbial \& plant assimilation}}$ Amino acids

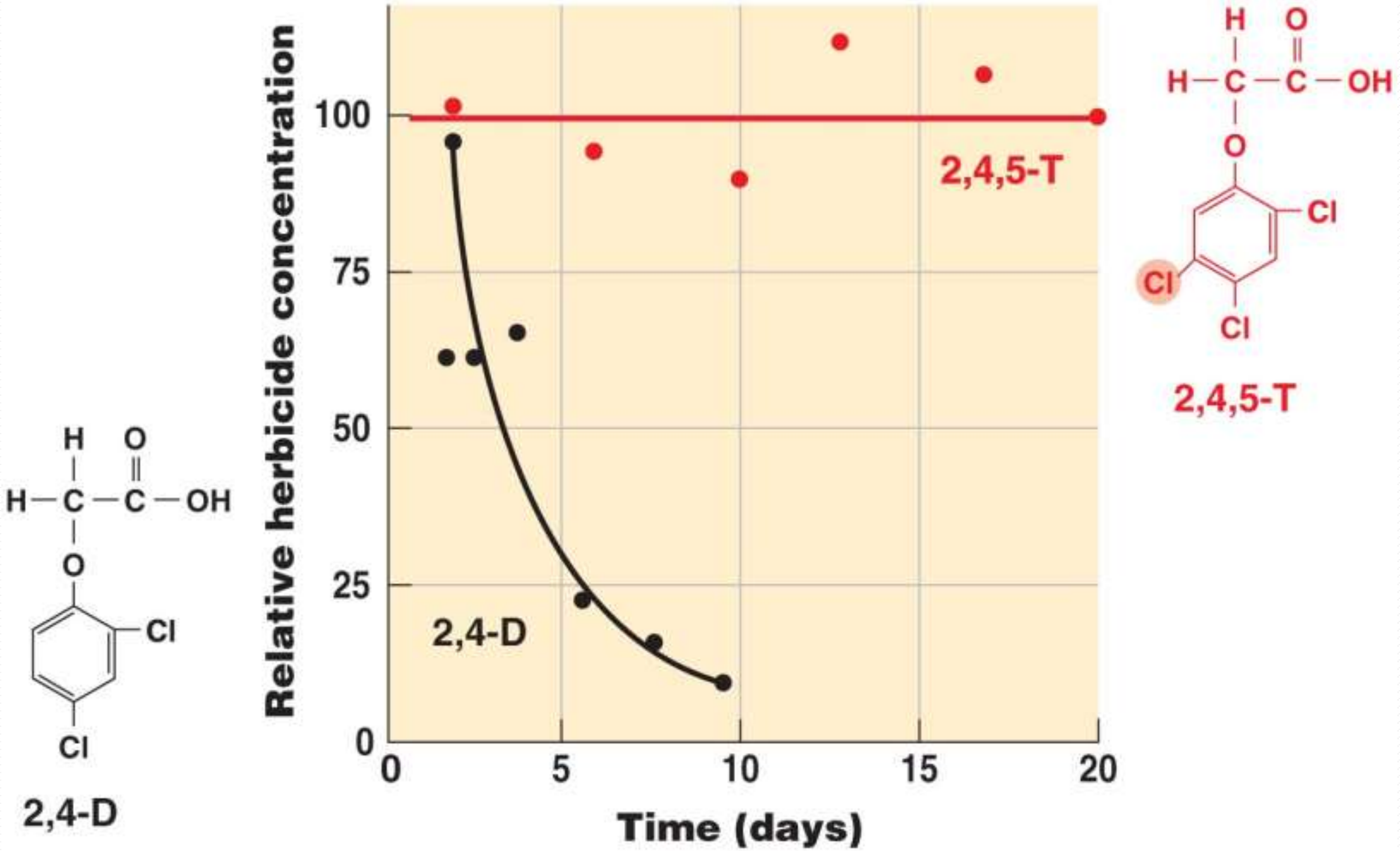
Soil microorganisms as biocontrol agents

- *Trichoderma* sp. and *Gleocladium* sp. are used for biological control of seed and soil borne diseases
- Fungal genera *Entomophthora, Beauveria, Metarrhizium* and protozoa *Maltesiagrandis Malameba locustiae* etc are used in the management of insect pests.
- Bacteria like *Bacillus thuringiensis*, *Pseudomonas* are used in cotton against Angular leaf spot and boll worms.

The Degradation/Detoxification of Synthetic Chemicals

- Natural organic matter is easily degraded by microbes
- **Degradation/detoxification of the toxic chemicals or pesticides:** bacterial genera like *Pseudomonas, Clostridium, Bacillus, Thiobacillus, Achromobacter* etc. and fungal genera like *Trichoderma, Penicillium, Aspergillus, Rhizopus, and Fusarium*
- **Biodegradation of hydrocarbons:** Natural hydrocarbons in soil like waxes, paraffin's, oils etc are degraded by fungi, bacteria and actinomycetes. E.g. ethane (C_2H_6) a paraffin hydrocarbon is metabolized and degraded by *Mycobacteria, Nocardia, Streptomyces, Pseudomonas, Flavobacterium* and several fungi

Microbial Decomposition of Herbicides



Prospectives of Microbes in soil

- **Bioremediation**: Use of microbes to detoxify or degrade pollutants; enhanced by nitrogen and phosphorus fertilizer
- **Bioaugmentation**: Addition of specific microbes to facilitate degradation of pollutant
- **Biostimulation:** Practice of addition of nitrogen and phosphorus to stimulate indigenous microorganisms in soil.
- **Bioventing:** Process/way of Biostimulation by which gases stimulants like oxygen and methane are added or forced into soil to stimulate microbial activity
- **Composting**:matter treated with aerobic thermophilic microorganisms to degrade contaminants

Impact of soil properties on microbes &Bioindication

- Nutrient
- Moisture
- Aeration
- pH
- Temperature

Threats to microbes in soil

- Soil degradation (erosion, Invasive specie, Global warming, Land use change, chemical pollution) which is accelerated by anthropogenic activities
- Climate driven factors such as temperature, precipitation, wind or rain intensity can contribute in the distribution of soil organic matter

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- soil compaction and reduction of soil porosity reduces of available habitats for soil organisms
- Alteration of soil aeration and humidity status due to soil compaction can seriously impact the activity of soil organisms.
- Oxygen limitation can modify microbial activity (favouring microbes that can withstand anaerobic conditions. This alters the types and distribution of all organisms found in the rest of the soil food web

Salinity

- salt concentration can affect the overall metabolism of plants and soil biota
- Many bacterial species have optimal salinity concentrations and enter a dormant state (dormancy) if the optimal range is exceeded, resulting in inactive states.
- extremely sensitive to salinisation.
- Lead to desertification and loss of soil biodiversity

Invasive species

- Urbanisation, land-use change in general and climate change, open up possibilities for species expansion and suggest that they will become a growing threat to soil biodiversity in the coming years.
- Invasive species can have major direct and indirect impacts on soil services and native biodiversity
- Invasive plants will alter nutrient dynamics and thus the abundance of microbial species in soil, especially of those exhibiting specific dependencies (e.g. mycorrhiza)

Anthropogenic influence on soil microbiota

- Anthropogenic processes that influence soil moicrobiota include:
  - Decreased OM: Conversion of (semi-)natural ecosystems to agriculture and changes in land use (e.g. conversion of arable to grassland). For instance, the conversion of natural to agricultural ecosystems usually causes depletion of 50 to 75% of the previous soil carbon pool.
  - Deep ploughing leads to organic matter dilution within soil. Agricultural ecosystems generally contain less SOC than their potential capacity because of the severe losses due to accelerated erosion and leaching and because of the increased respiration rate in ploughed soils, due to the enhanced aerobic status of deeper soil layers

Possible impacts of chemical pollution on soil biodiversity and its impacts on soil organisms

Chemical pollutant	Affected soil organisms	Affected soil function	Affected soil service
Pesticides	Biological regulators, chemical engineers	OM decomposition, mineralisation	Nutrient cycling, soil fertility, water regulation
GM plants	Chemical engineers	Mineralization, OM decomposition	Nutrient cycling, soil fertility
Industrial chemicals	Chemical engineers		Nutrient cycling, soil fertility

Cont’d

- Artificial removal or decrease of litter due to land conversion (e.g. deforestation)
- Forest fires
- Over-grazing

Chemical pollutants

- degradation of the pesticide effects active saprotrophic fungi
- microbial respiration
- nutrient transformation
- enzymatic activity (i.e. alteration in the efficiency in pesticide sulphonyl ureas, for instance targets the enzymes involved in the synthesis of the amino acids valine, leucine and isoleucine harms bacteria and fungi due to high concentrations

Use of Agrochemicals

- overuse of some of these chemicals changes soil composition and disrupts the balance of microorganisms in the soil
- stimulates the growth of harmful bacteria at the expense of beneficial kinds

GMOs

- Horizontal transfer of genes between soil micro-organisms may be facilitated by vector DNA from genetically engineered plants, resulting in such changes or disturbances in the functioning of the micro-organisms that soil ecology and fertility may be affected
- cumulative loss of soil biodiversity and decreased fertility
  - E.g transgenic *cyanobacteria* carrying the *BT* gene and BT toxin production in soil

Land sealing

- soils covered by impermeable layers of asphalt, concrete or other sealing materials.
- lead to a slow death of most soil organisms due to nutrient depletion and disturbance of biochemical cycles
- In the future, soil sealing is expected to continue at an increasing rate

Thank you!