The Role of Soil Microbes in Providing Plant-Available Nitrogen

Practical Training on Nitrogen Management in Organic Production of Annual Crops

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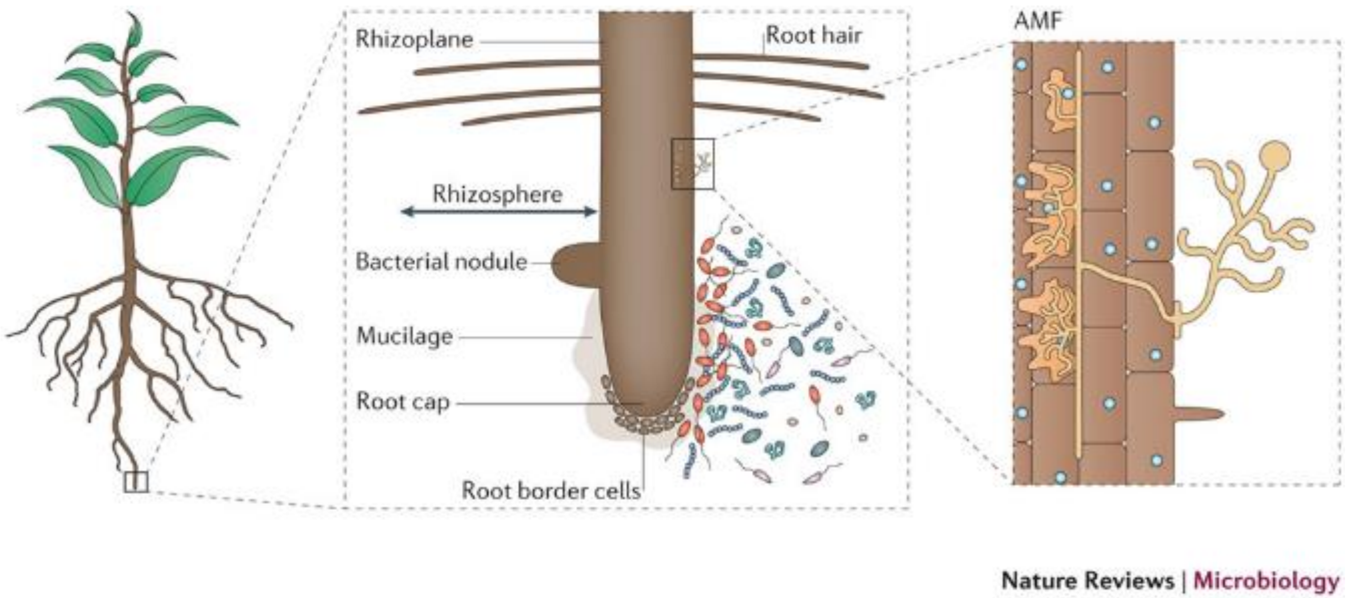
Outline

- Root uptake of soil nitrogen and use of nitrogen in the plant
- Close-up look at roots and soil microbes in the soil
- How and why soil microbes produce plant-available nitrogen
- Ways that microbial symbioses improve nitrogen cycling



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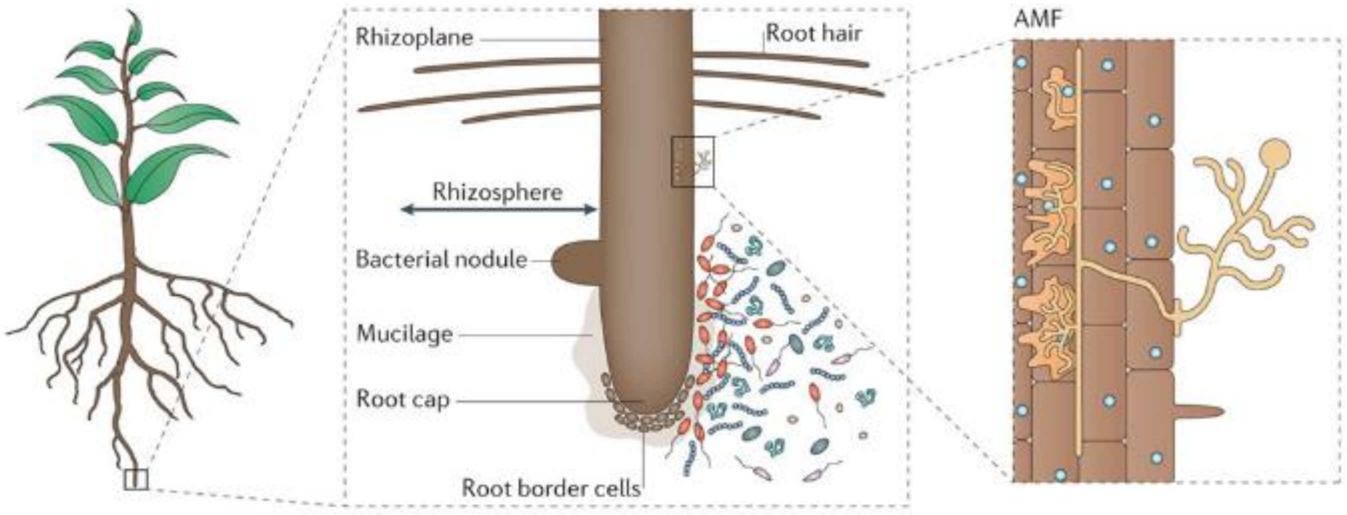

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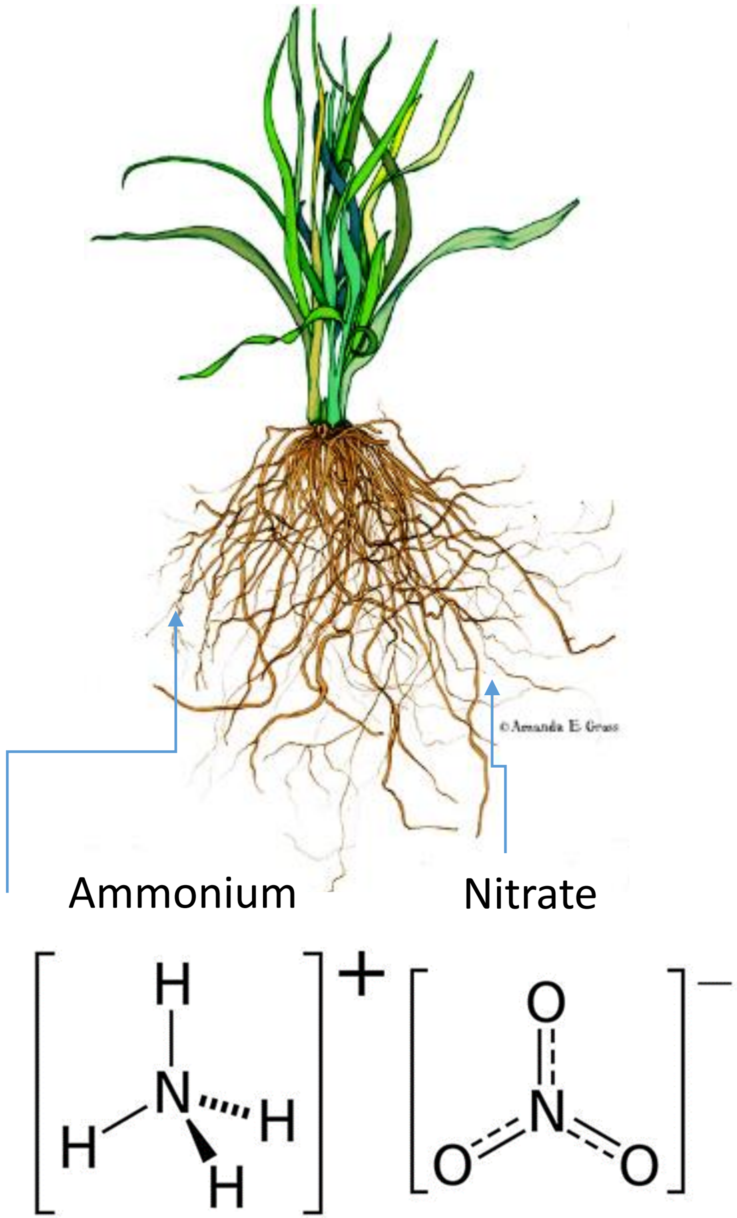
Nitrogen uptake by plants

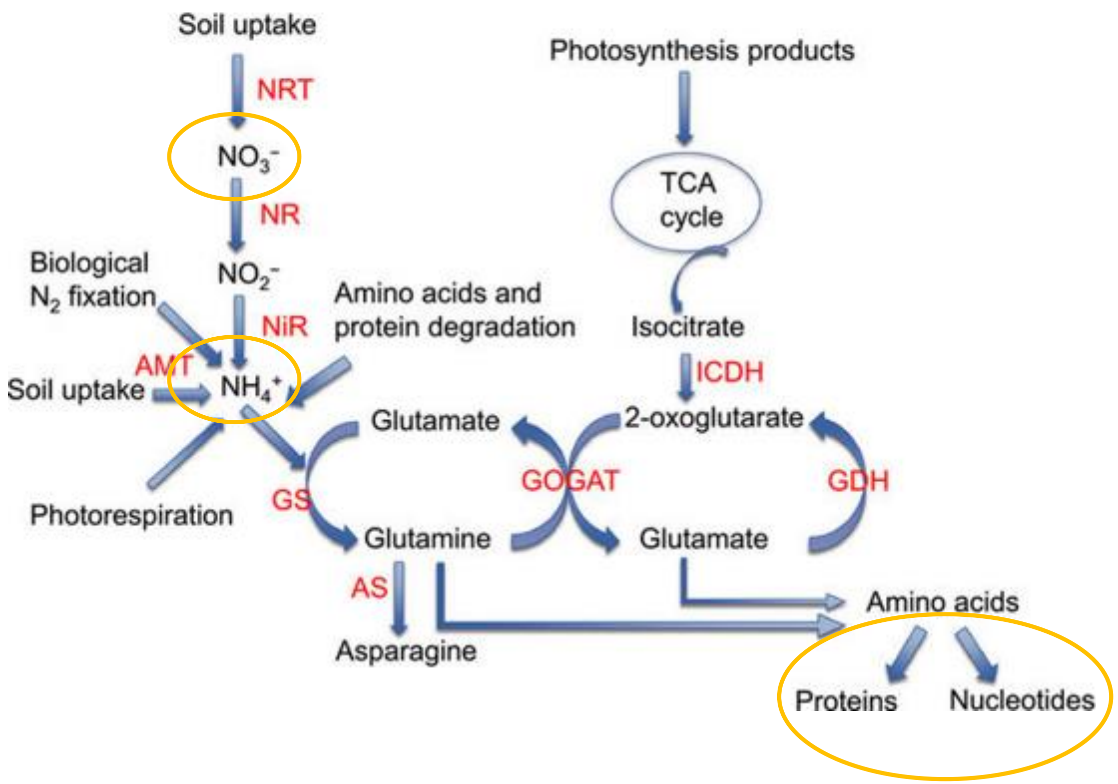
- Ammonium (NH_4+) and nitrate (NO_3-) are the N forms taken up by roots of annual plants
- A mix of both N forms is desirable to avoid ammonium (NH_4+) toxicity and maintain a neutral pH in the plant
- Organic forms of N (containing both N and C) are of very limited use by annual crops



Nitrogen utilization in the plant

- Nitrate (NO_3-) must be reduced to ammonium (NH_4+) to be used by the plant, such as for protein production
- These steps demand a great deal of energy

From soil N uptake to plant proteins



The plant builds its organic matter from N and C, using energy from photosynthesis.

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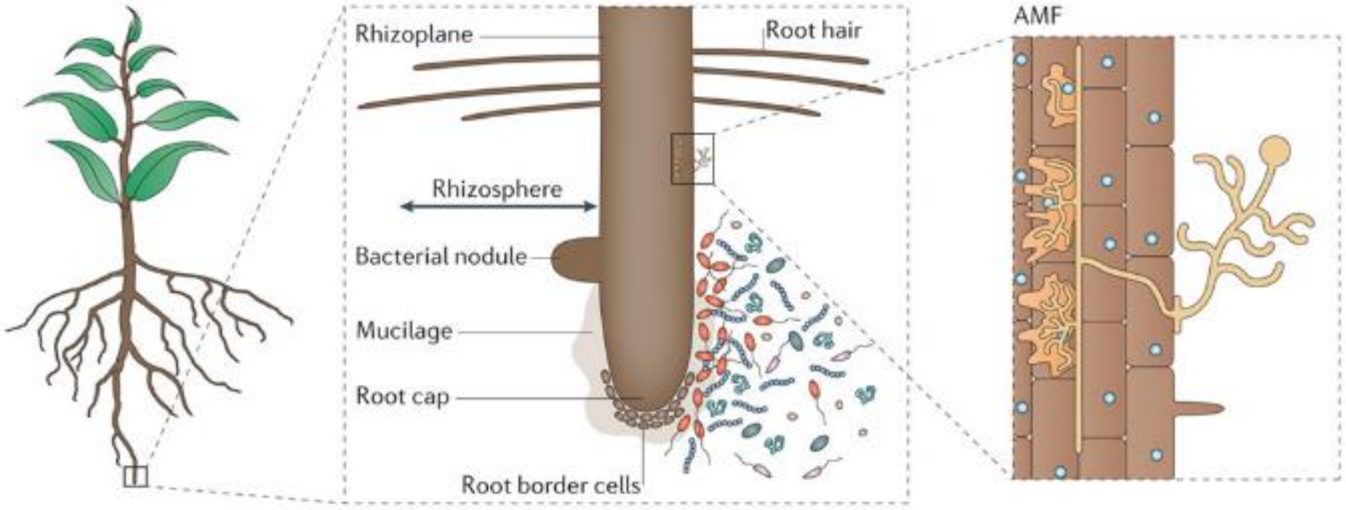
- **How and why soil microbes produce plant-available nitrogen**
- Opportunities for improving plant-soil-microbe nitrogen cycling



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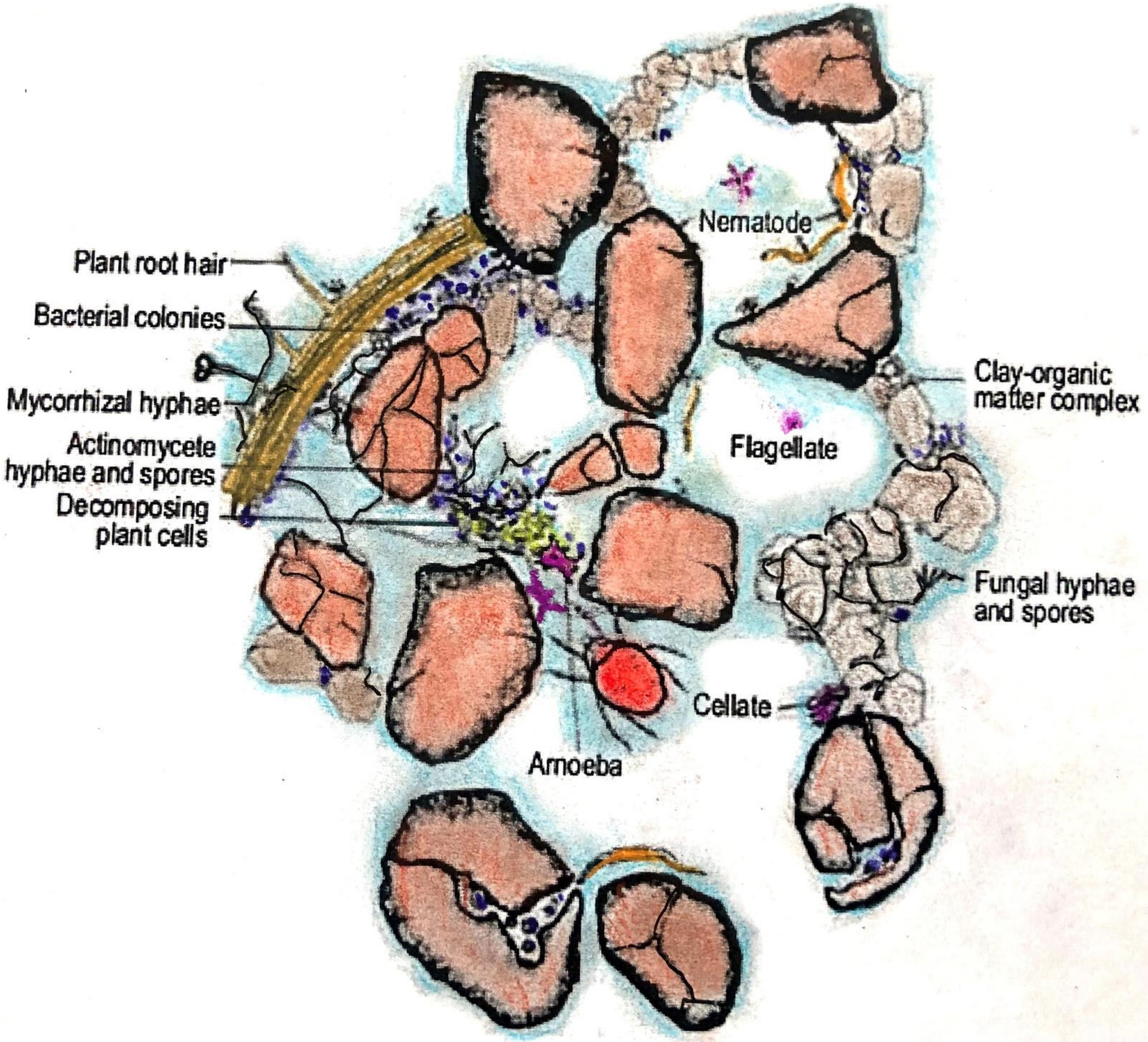
Close-up view of a soil aggregate

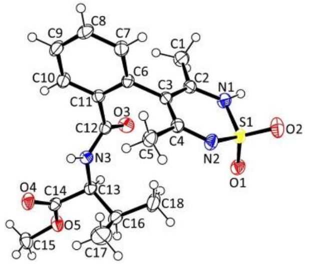


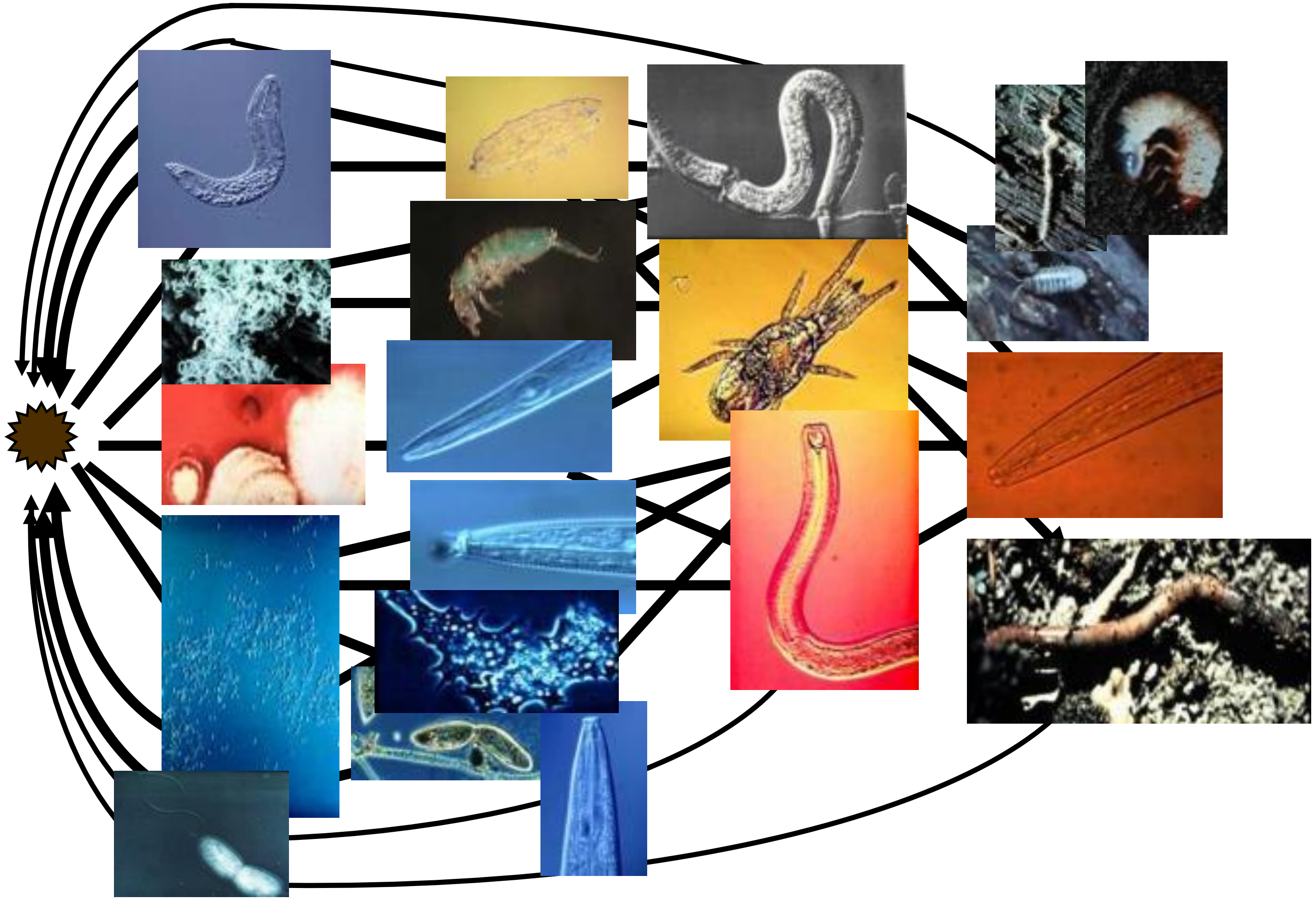
S. Rose and E.T. Elliott

Soil food chain

- Soil microbes use the C and N in organic matter
- Predators toward the right consume prey on the left
- The consumption of prey produces organic matter, such as from waste products

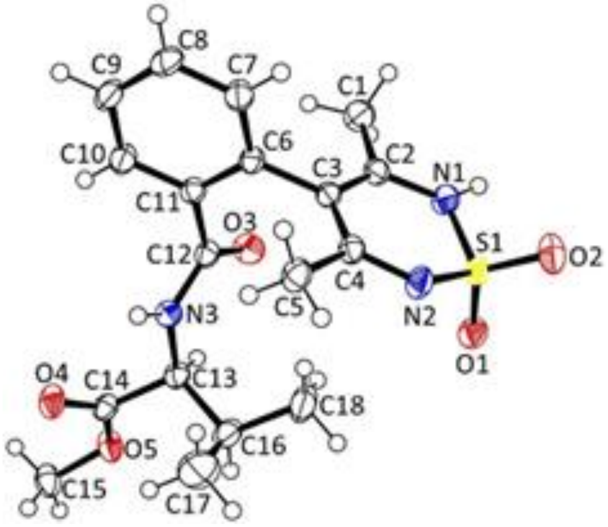
Organic matter





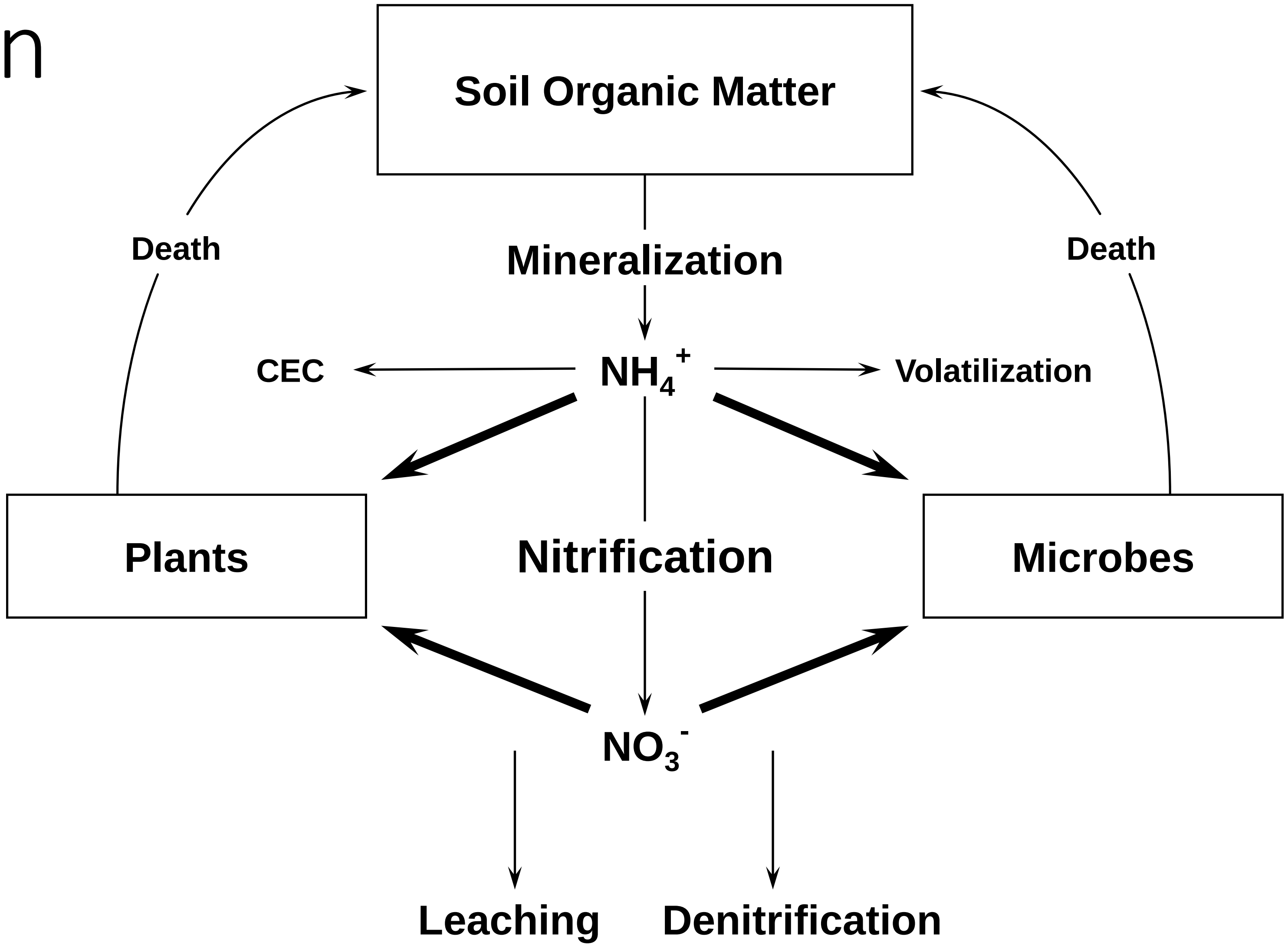
The turnover of soil organisms in the food chain helps to maintain a reliable supply of active organic matter and plant-available nitrogen

Soil organic matter (SOM)



- Mainly composed of C, N, O, H
- **Most abundant**: recalcitrant and protected SOM
  - Humic substances and other material that is hard for microbes to break down
  - Physically or chemically protected to resist breakdown
- **Much less abundant**: active SOM
  - Sugars, amino acids, readily decomposable plant material, dead and live microbial cells….
- Microbes break down SOM to get soluble, available C for their growth and maintenance. N is also released.

Plant-soil nitrogen cycle



Soil microbial nitrogen transformatons

- **Mineralization**: microbial breakdown of soil organic matter (SOM) that results in ammonium (NH_4+) release
- **Nitrogen immobilization**: microbial uptake of organic or mineral N to meet nutritional needs
- **Nitrification**: microbes rely upon ammonium as an energy source; ammonium (NH_4+) is oxidized to nitrate (NO_3-)
- **Denitrification**: under waterlogged or anaerobic conditions in soil, microbes reduce nitrate (NO_3-) to release of N_2 gas or nitrous oxide (a greenhouse gas)

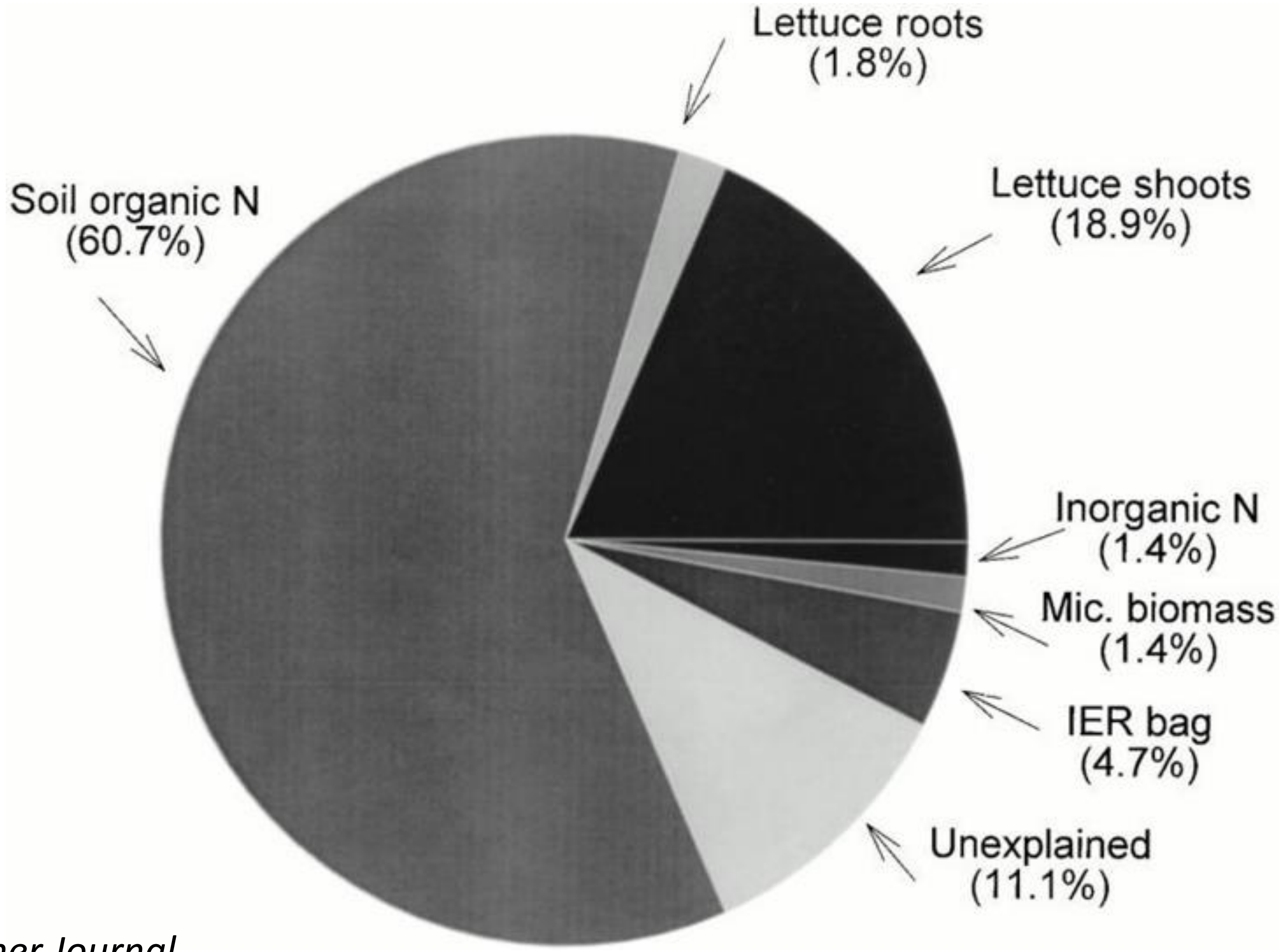
What happens to cover crop N on Chualar loamy sand?

Methods for ^{15}N *Phacelia* tracer experiment

- Roots and shoots of *Phacelia* incorporated into soil cylinders in March
  - 11.4 g N m^{-2}, *i.e.*, 101 lbs N acre^{-1}
  - Contained 13.4 atom percent ^{15}N
- Iceberg lettuce seeded in April (45 days later) and harvested in mid-July
  - Fertilizer of 8.4 g N m^{-2} added, *i.e.*, 75 lbs N acre^{-1}
  - Water inputs of 42 cm, *i.e.*, 16 inches
- Second iceberg lettuce crop grown with similar inputs

Inorganic N (2N KCl extracts); Microbial biomass C and N (chl. fumigation-extraction): Ion exchange resin bags (extracted in KCl); Soil organic N and plant N by combustion; Diffusion technique to prepare samples for ^{15}N analysis; Analysis on mass spectrometer at UC Davis

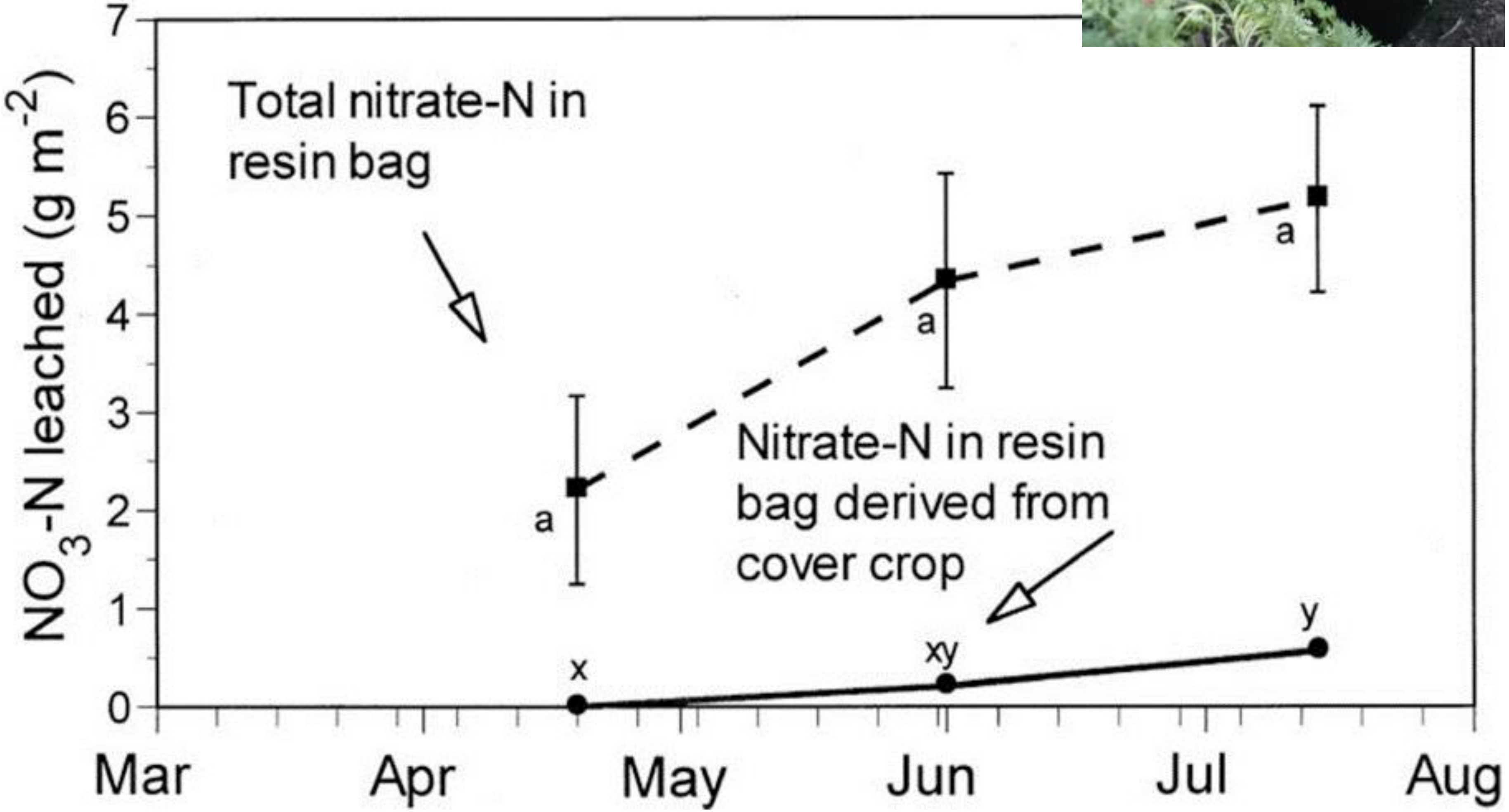
Fate of *Phacelia* ^{15}N after first lettuce crop (%)



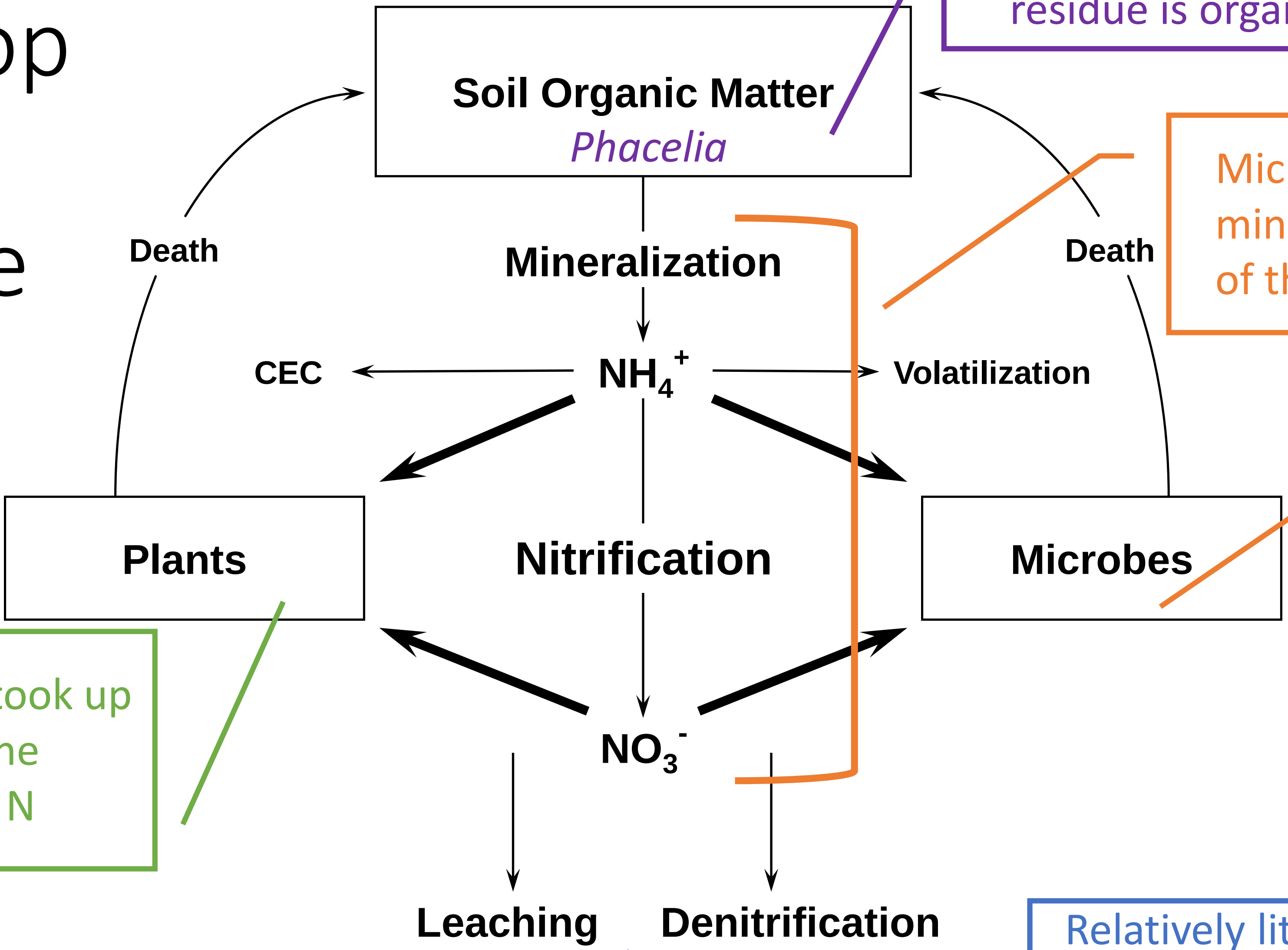
Jackson. 2000. *Soil Sci Soc of Amer Journal*

Leaching of cover crop N

Ion exchange resin bags (IER bags) trapped nitrate that leached to 2-ft depth in the soil profile



Fate of cover crop nitrogen at lettuce harvest



60% of the N from *Phacelia* residue is organic matter

Microbes mineralized 40% of the *Phacelia* N

Little storage of *Phacelia* N in microbes; high turnover

Lettuce took up 20% of the *Phacelia* N

Relatively little loss of *Phacelia* N occurred

Management implications

- Soil microbes require easily degradable organic matter to supply crop plants with N
  - Sources include crop residues, dead microbes, root exudates, soil food chain wastes of prey consumption, some compounds in compost and manure
- Low concentrations of soil ammonium (NH_4+) and nitrate (NO_3-) can be OK if organic matter mineralization and plant uptake is rapid
  - Test to see if the crop has adequate levels of total N
  - Petiole nitrate (NO_3-) is not always a dependable assay in organic vegetables
- To minimize nitrate (NO_3-) losses, grow and incorporate cover crops and cash crop residues suited for different phases of the farm's cropping system

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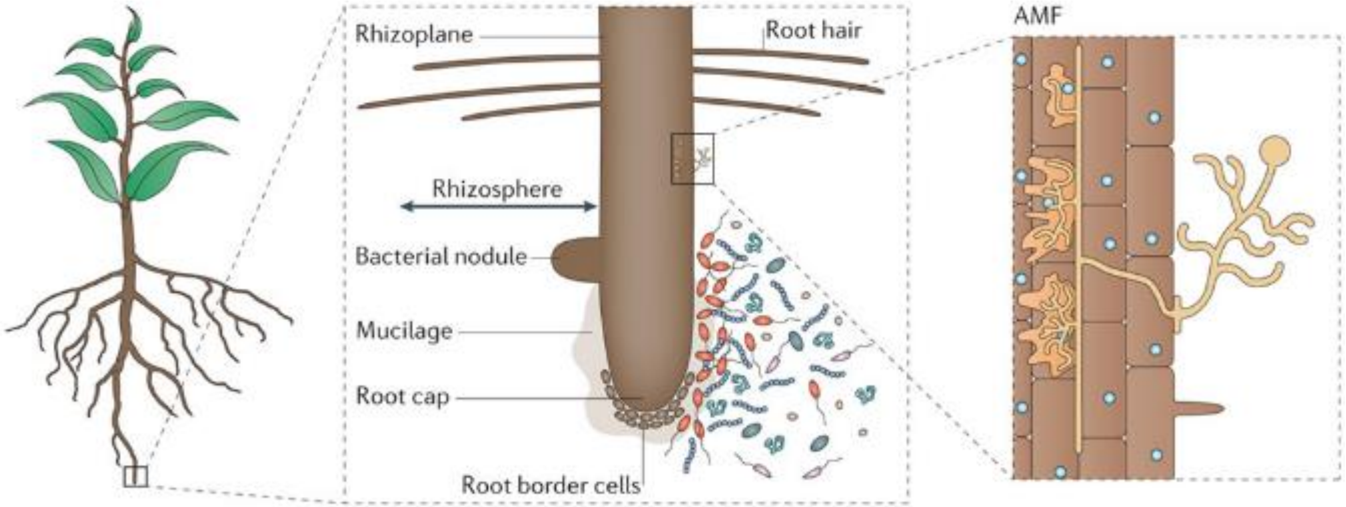

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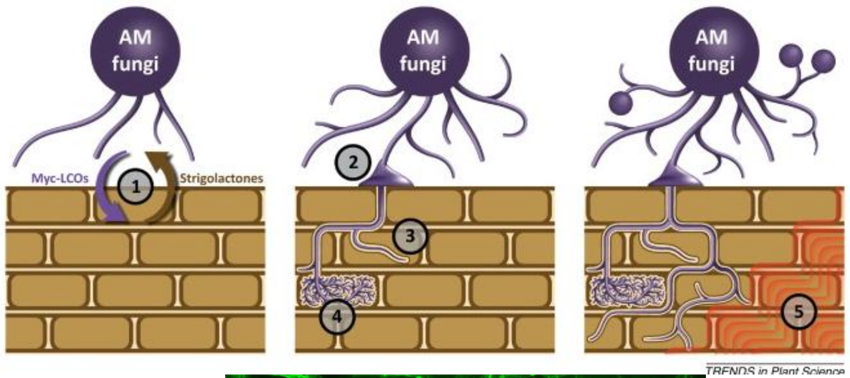
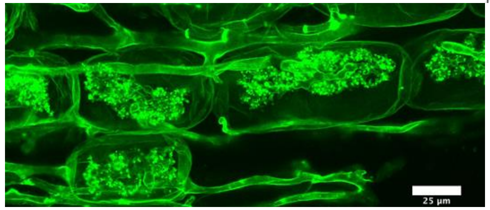
Arbuscular mycorrhizal fungal (AMF) symbiosis

Functions

- Roots supply C to fungus; fungus supplies nutrients to root
- Hyphae scavenge nutrients from a larger soil volume than roots alone
- Increase in shoot nutrients (N, P, Zn)
- Decrease in soil nitrous oxide emissions





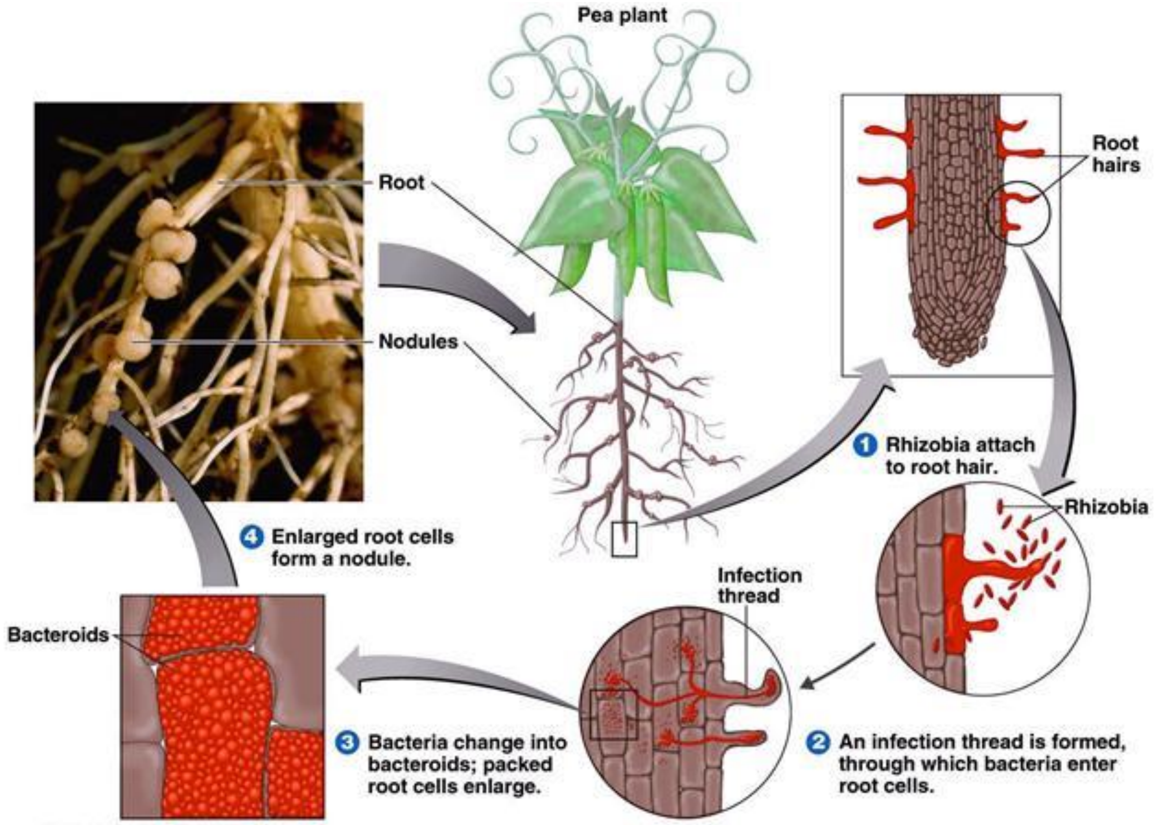
Management to promote benefits from the symbiosis

- More crops in the rotation with the ability to form the symbiosis
- Time since transition from conventional production
- Continuous cropping, less tillage, less fallow

N fixation by legumes

Functions

- Bacterial nodules form from root cells
- Ammonium (NH_4+) is produced from N_2
- High energy demand
- Source of N to the legume plant and to the soil as its residues decompose



Management to promote benefits from the symbiosis

- Use legume cover crops in mixtures with higher C:N species
- Avoid a long lag between legume cover crop and crop to minimize N loss from soil
- Transplants may be better than direct-seeded crops at obtaining legume-derived N

Conclusions

- Overall goal is adequate crop N uptake and growth with:
  - High N mineralization of SOM at peak crop N demand
  - Rapid plant uptake of ammonium (NH_4+) and nitrate (NO_3-)
  - Lower losses of soil nitrate (NO_3-)
- To increase the role of soil microbes in providing plant-available N:
  - Active soil organic matter and dynamic soil food web
  - Microbial symbioses within roots
  - Environmental conditions in soil aggregates, including soil texture