

Nutrients

October 15, 2019

Biologically essential nutrients

Table 8.1 Nutrients required by plants and their major functions

Nutrient	Role in plants
Macronutrients	Required by all plants in large quantities
<i>Primary</i>	Usually most limiting because used in largest amounts
Nitrogen (N)	Component of proteins, enzymes, phospholipids, and nucleic acids
Phosphorus (P)	Component of proteins, coenzymes, nucleic acids, oils, phospholipids, sugars, starches Critical in energy transfer (ATP)
Potassium (K)	Component of proteins Role in disease protection, photosynthesis, ion transport, osmotic regulation, enzyme catalyst
<i>Secondary</i>	Major nutrients but less often limiting
Calcium (Ca)	Component of cell walls Regulates structure and permeability of membranes, root growth Enzyme catalyst
Magnesium (Mg)	Component of chlorophyll Activates enzymes
Sulfur (S)	Component of proteins and most enzymes Role in enzyme activation, cold resistance
Micronutrients	Required by all plants in small quantities
Boron (B)	Role in sugar translocation and carbohydrate metabolism
Chloride (Cl)	Role in photosynthetic reactions, osmotic regulation
Copper (Cu)	Component of some enzymes, role as a catalyst
Iron (Fe)	Role in chlorophyll synthesis, enzymes, oxygen transfer
Manganese (Mn)	Activates enzymes, role as a catalyst
Molybdenum (Mo)	Role in N fixation, NO _x enzymes, Fe absorption, and translocation
Zinc (Zn)	Activates enzymes, regulates sugar consumption
Beneficial nutrients	Required by certain plants or by plants under specific environmental conditions
Aluminum (Al)	
Cobalt (Co)	
Iodine (I)	
Nickel (Ni)	
Selenium (Se)	
Silicon (Si)	
Sodium (Na)	
Vanadium (V)	

Reprinted from Chapin and Eviner (2004)

Nutrients limit productivity (primarily N and P)

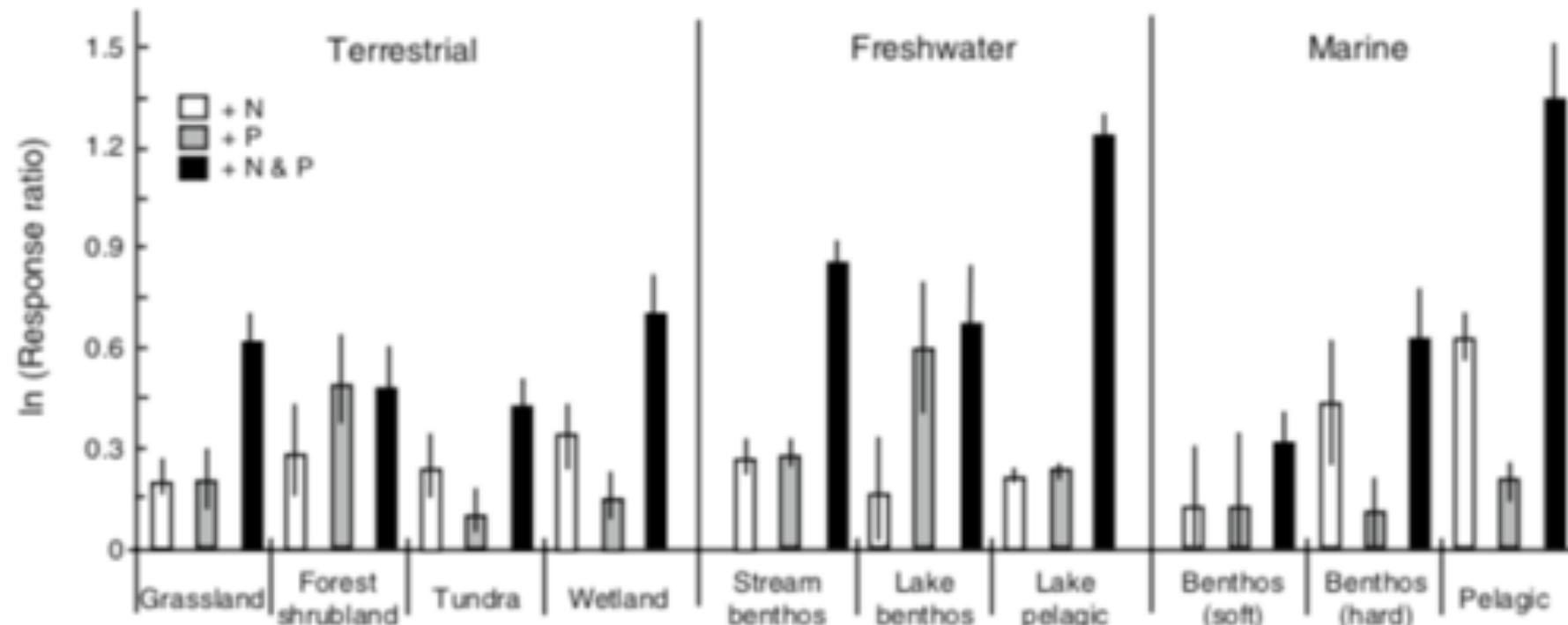


Fig. 8.3 Relative response of plant production to addition of nitrogen or phosphorus or to both nutrients in major habitat types of terrestrial, freshwater, and marine ecosystems. Relative response is calculated as the biomass or

production in the enriched treatment divided by its value in the control treatment and then ln-transformed. Redrawn from Elser et al. (2007)

Nutrient cycling

Nutrients cycle through ecosystems differently

Table 8.2 Major sources of nutrients that are absorbed by terrestrial plants

Nutrient	Source of plant nutrient (% of total)		
	Deposition/ fixation	Weathering	Recycling
Temperate forest (Hubbard Brook)			
Nitrogen	7	0	93
Phosphorus	1	< 10?	> 89
Potassium	2	10	88
Calcium	4	31	65
Tundra (Barrow)			
Nitrogen	4	0	96
Phosphorus	4	< 1	96

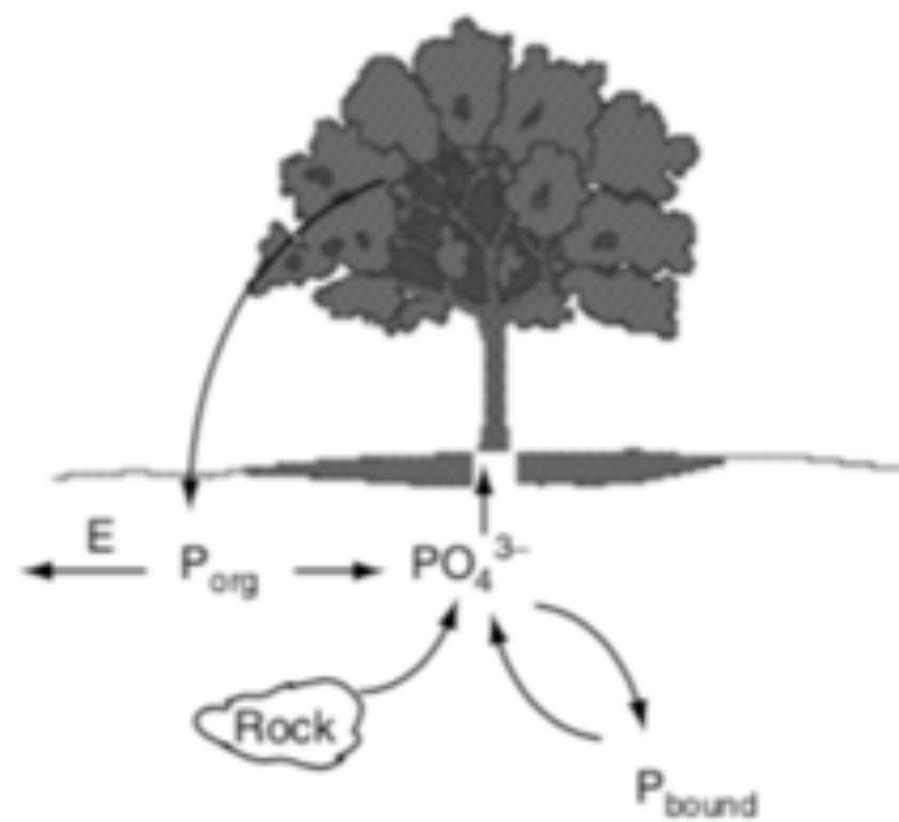
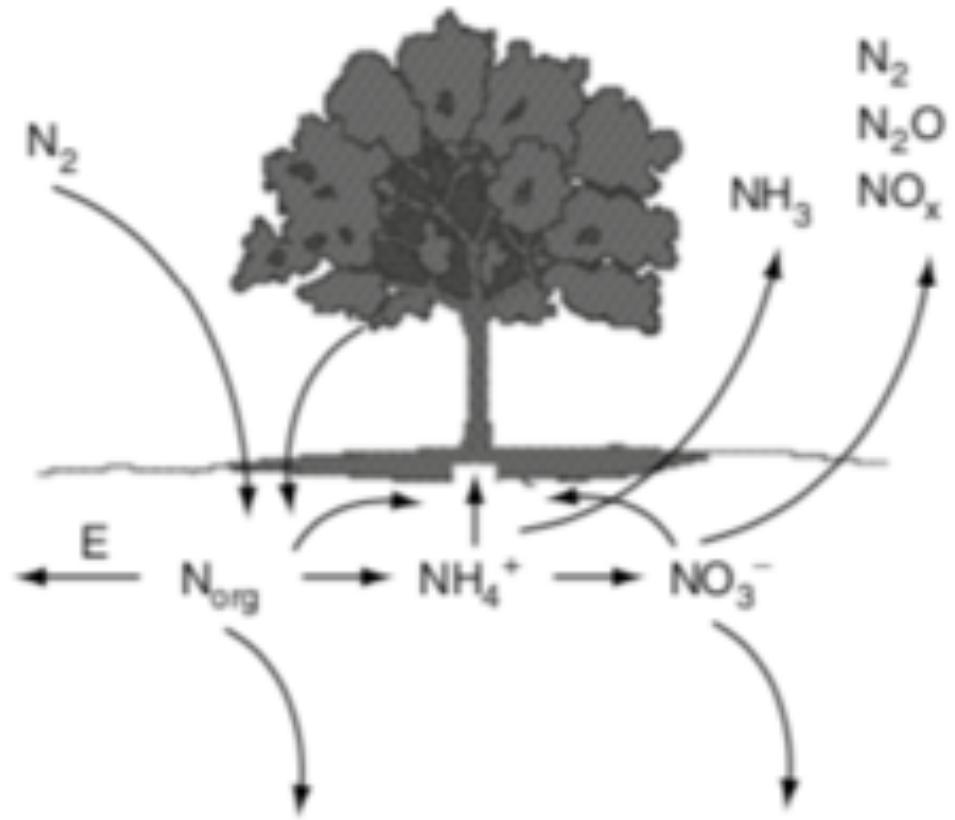
Data from Chapin (1991b)

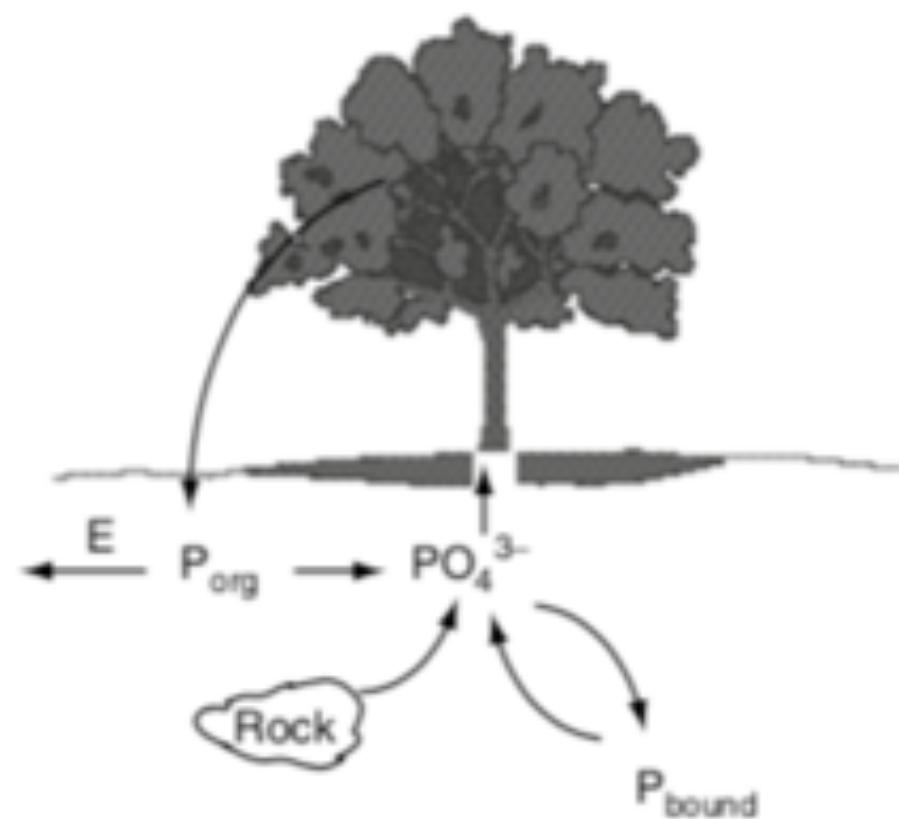
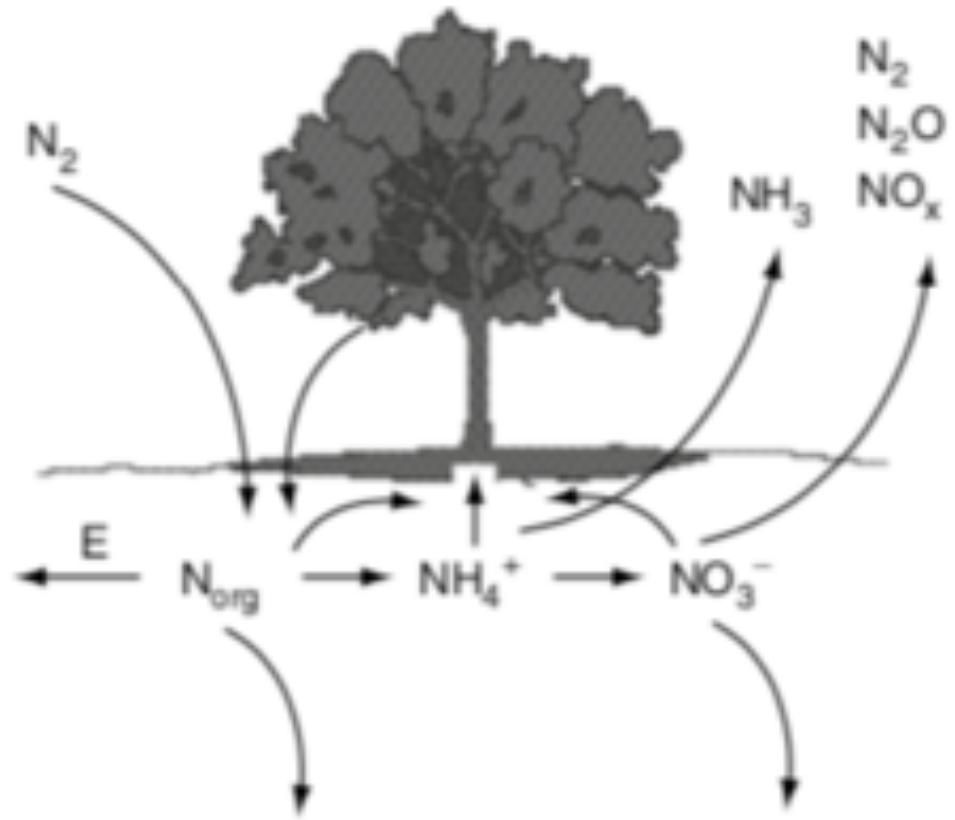
Nutrients cycle through ecosystems differently

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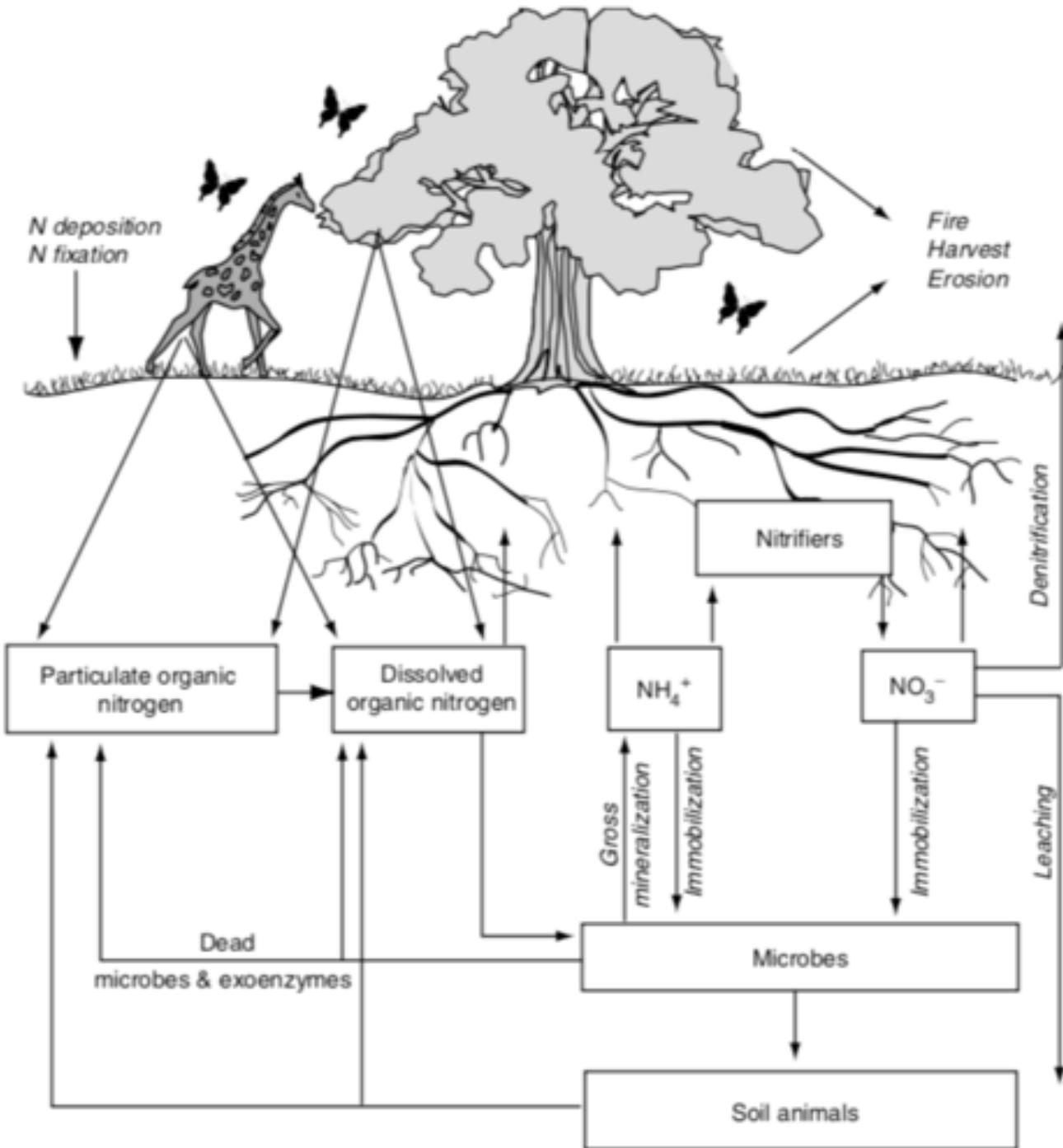
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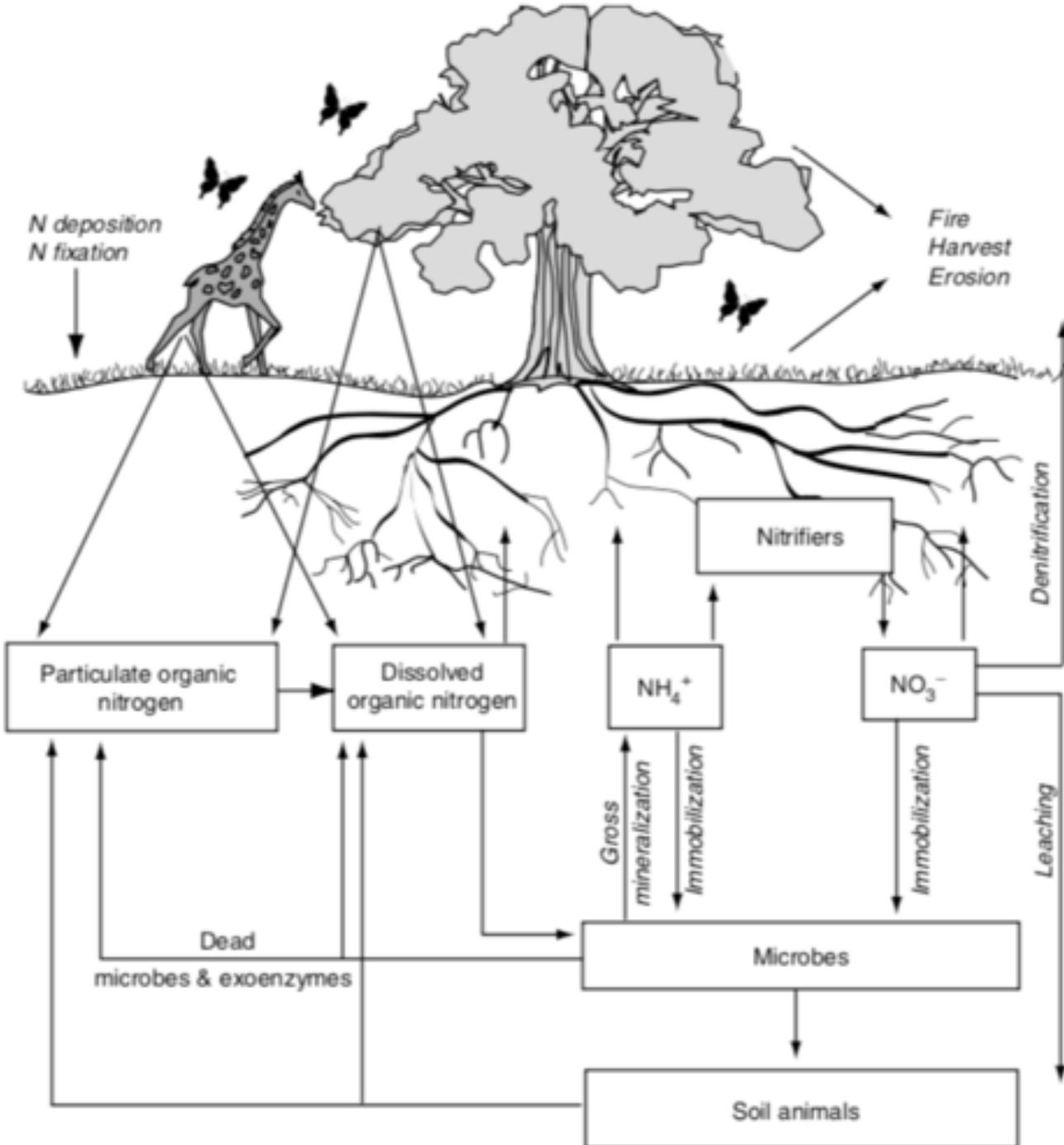


The terrestrial N cycle

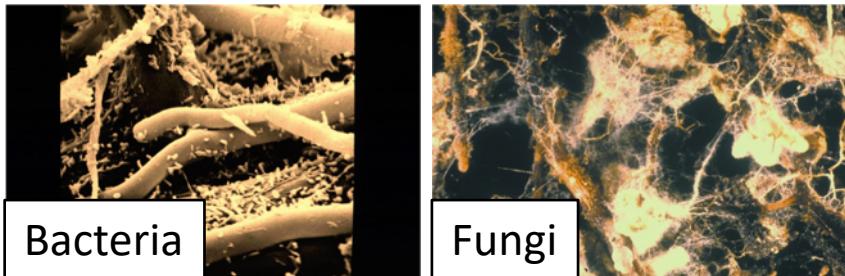


The terrestrial N cycle

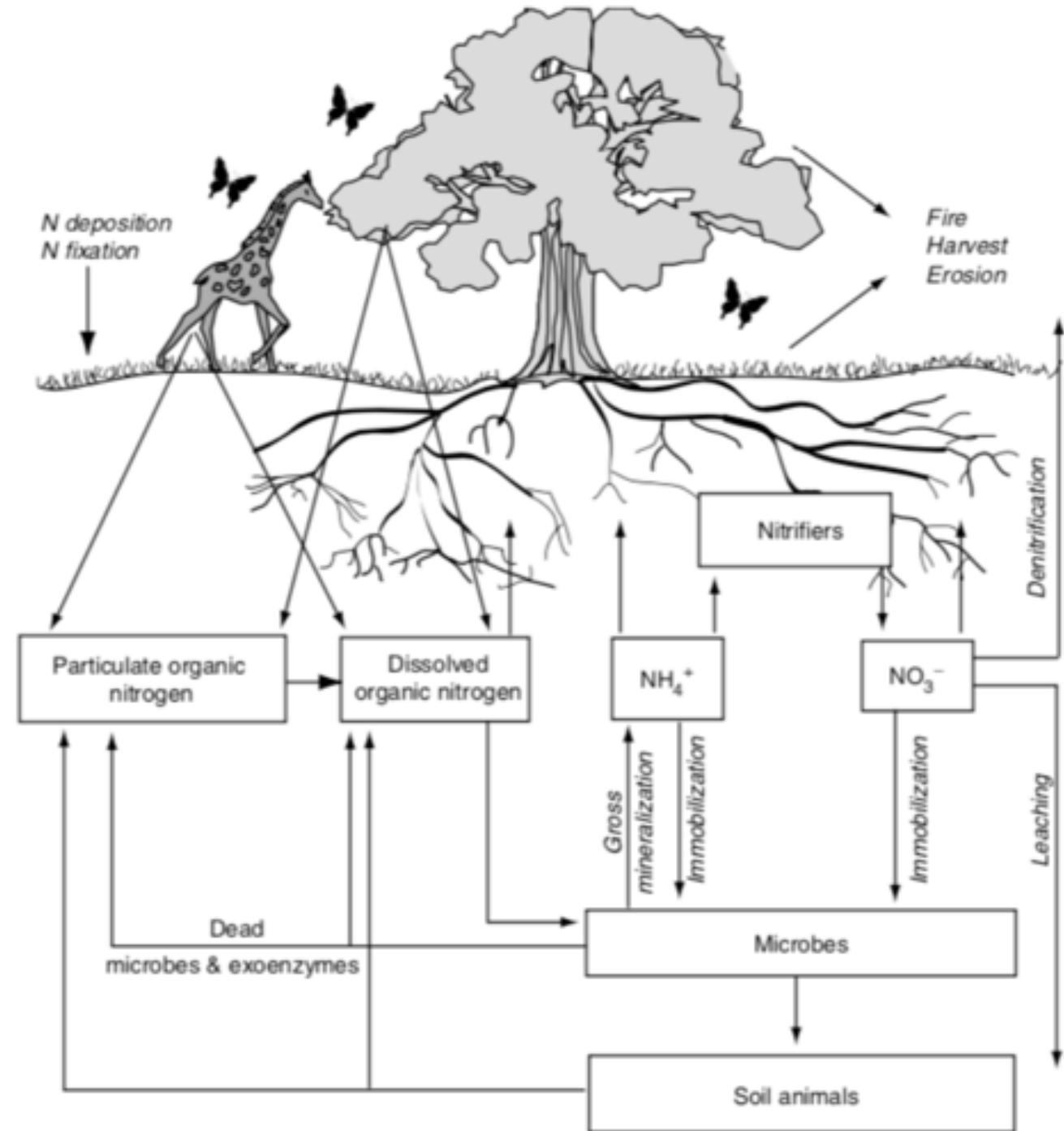
Nitrogen is
constantly changing
forms due to
biological organisms



The terrestrial N cycle

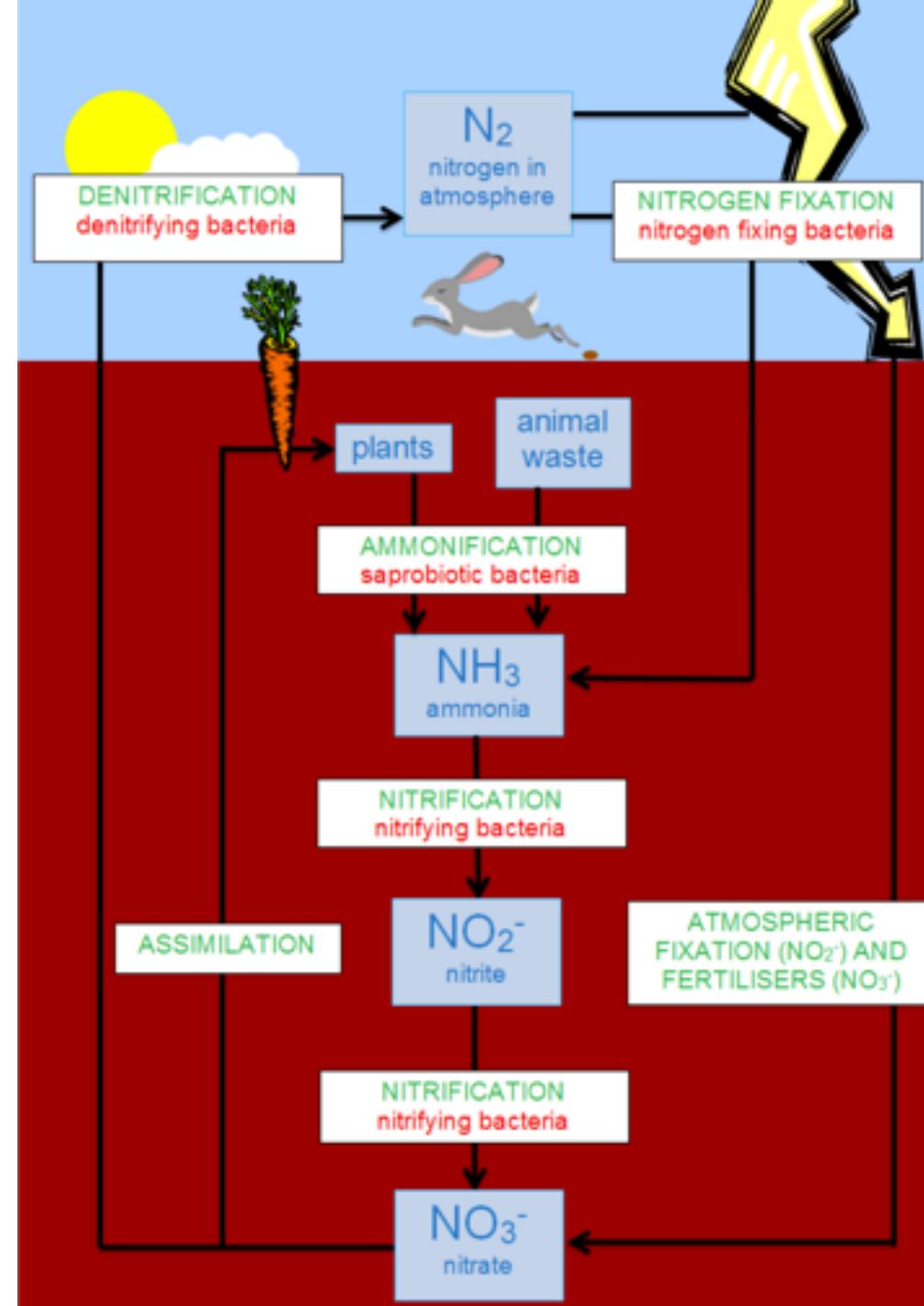


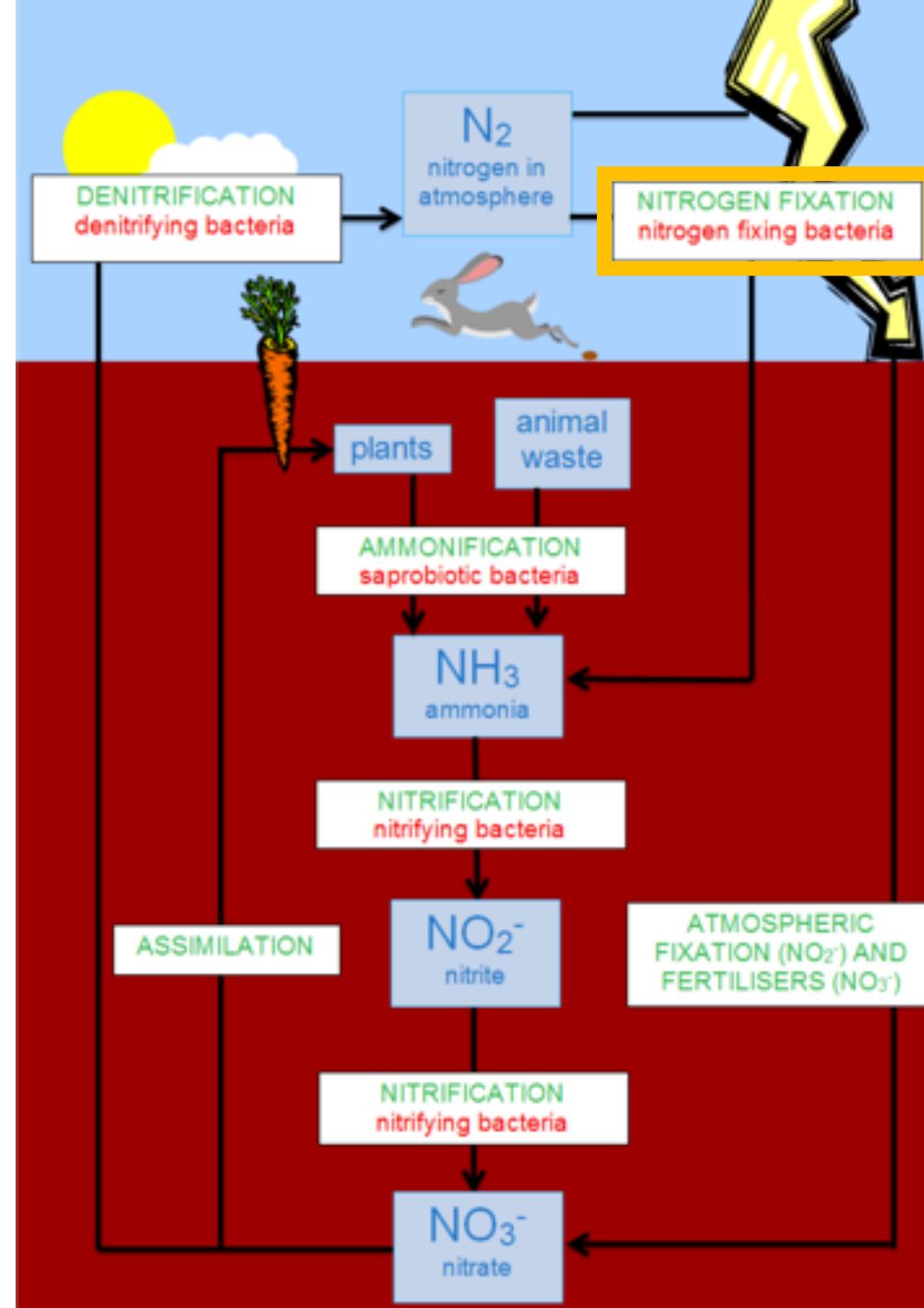
Nitrogen is constantly changing forms due to biological organisms (mostly microbes)



Important N forms

- N_2
 - Nitrogen **gas**
 - Lots in the atmosphere
 - Cannot be taken up by plants or most microbes (just N fixers)
- NO_3^-
 - Nitrate
 - Highly mobile
 - Can be easily taken up by plants and most microbes
- NH_4^+
 - Ammonium
 - Mobile
 - Can be easily taken up by plants and most microbes
- **Dissolved organic N (DON)**
 - Organic (contains C)
 - Produced by dead organisms
 - Cannot be taken up by plants
 - Can be broken down by microbes





Biological N fixation: $\text{N}_2 \rightarrow \text{NH}_3$

Table 9.1 Organisms and associations involved in di-nitrogen fixation

Type of association ^a	Key characteristics	Representative genera
Heterotrophic N fixers		Bacteria
Associative		
Nodulated (symbiotic)	Legume	<i>Rhizobium</i>
	Nonlegume woody plants	<i>Frankia</i>
Non-nodulated	Rhizosphere	<i>Azotobacter, Bacillus</i>
	Phyllosphere	<i>Klebsiella</i>
Free-living	Aerobic	<i>Azotobacter, Rhizobium</i>
	Facultative aerobic	<i>Bacillus</i>
	Anaerobic	<i>Clostridium</i>
Phototrophic N fixers		Cyanobacteria
Associative	Lichens	<i>Nostoc, Calothrix</i>
	Liverworts (<i>Marchantia</i>)	<i>Nostoc</i>
	Mosses	<i>Holosiphon</i>
	Gymnosperms (<i>Cycas</i>)	<i>Nostoc</i>
	Water fern (<i>Azolla</i>)	<i>Nostoc</i>
Free-living	Cyanobacteria	<i>Nostoc, Anabaena</i>
	Purple non-sulfur bacteria	<i>Rhodospirillum</i>
	Sulfur bacteria	<i>Chromatium</i>



Heterocysts

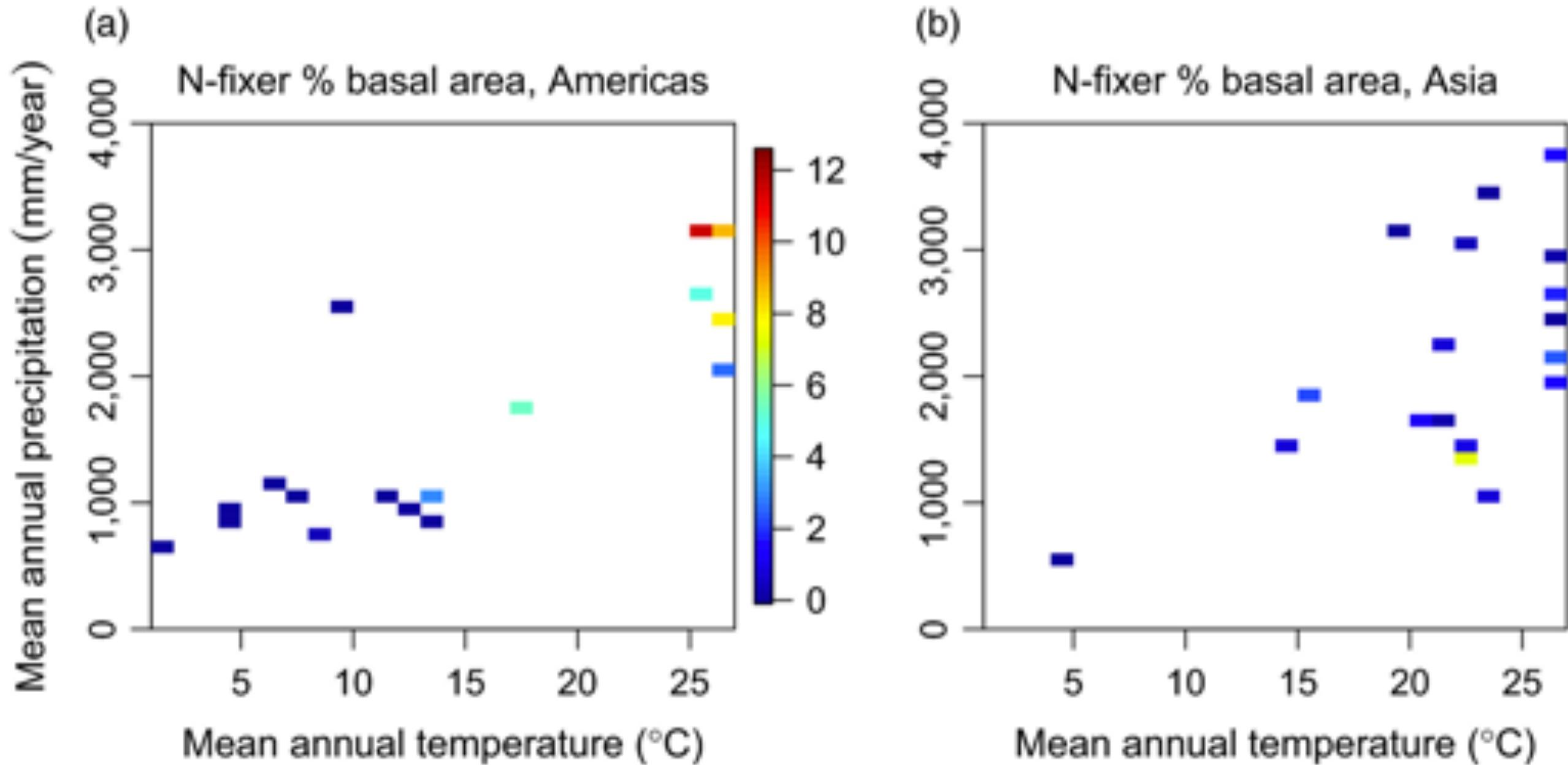
Nodules

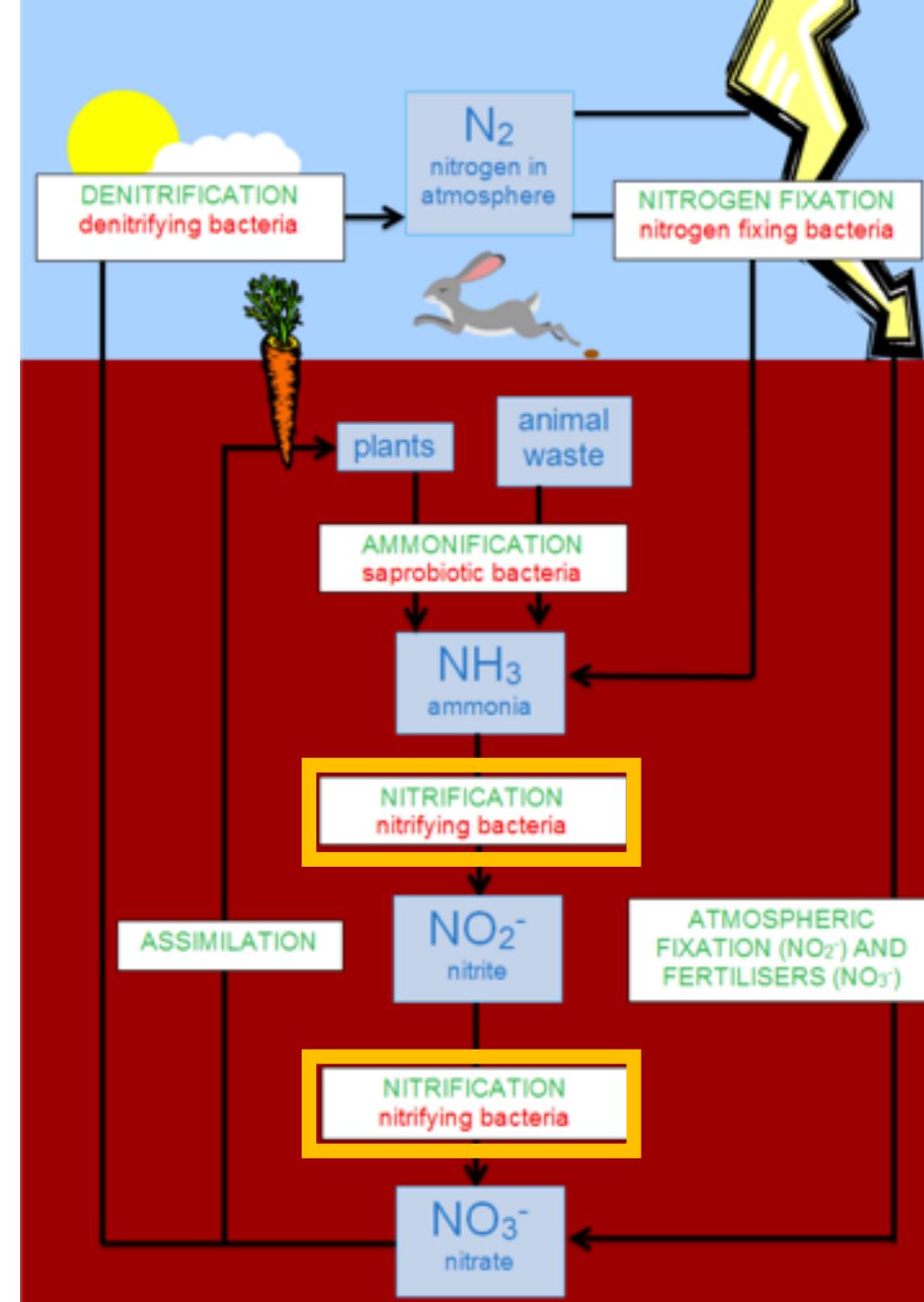


Soil Aggregates

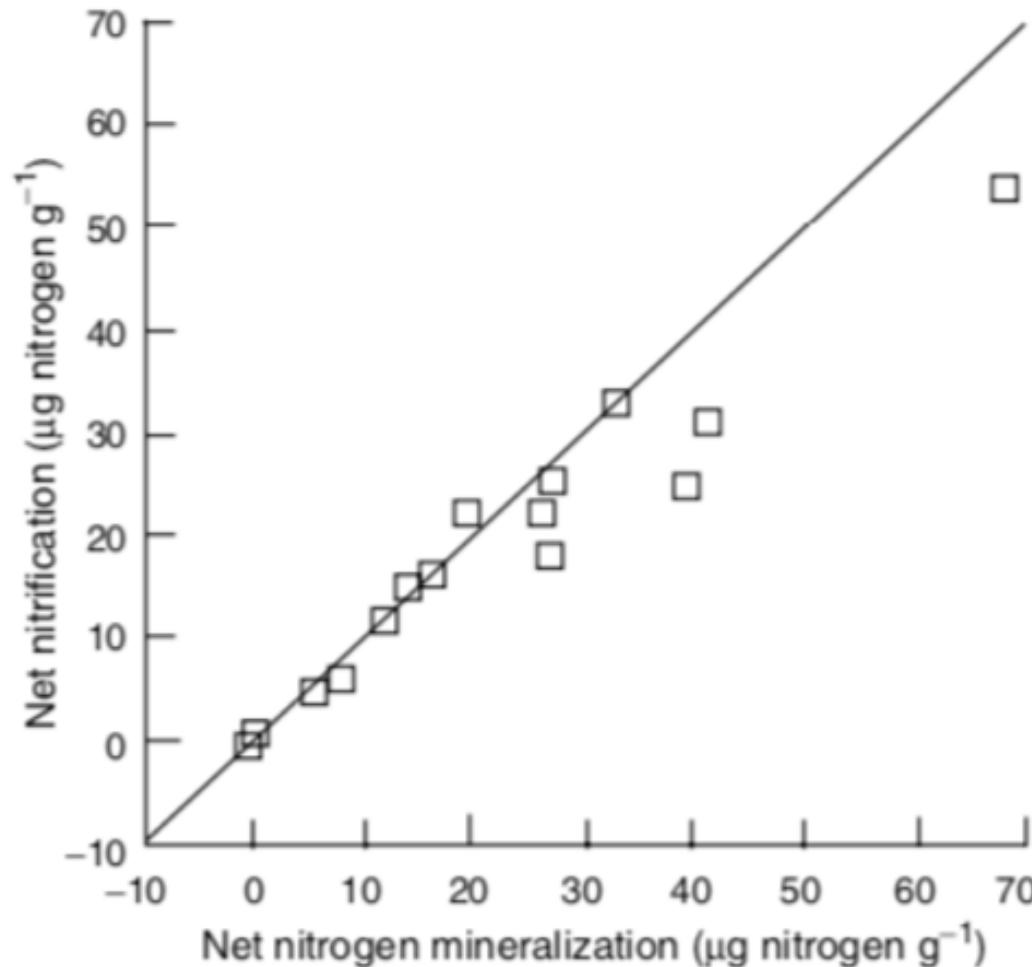
Questions to ponder

- Why wouldn't all plants associate with N fixing bacteria?
- Where would you expect to find plants that associate with N fixing bacteria?



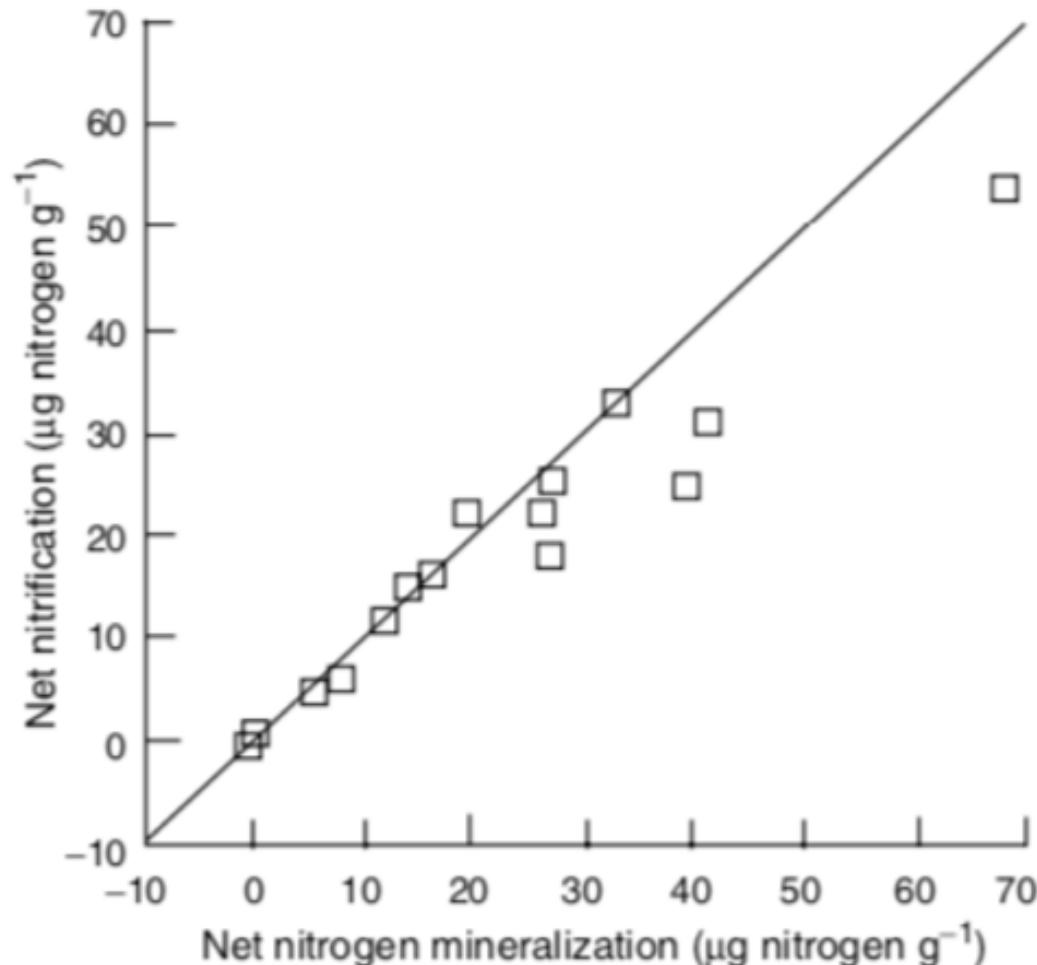


Nitrification: $\text{NH}_3 \rightarrow \text{NO}_2 \rightarrow \text{NO}_3$



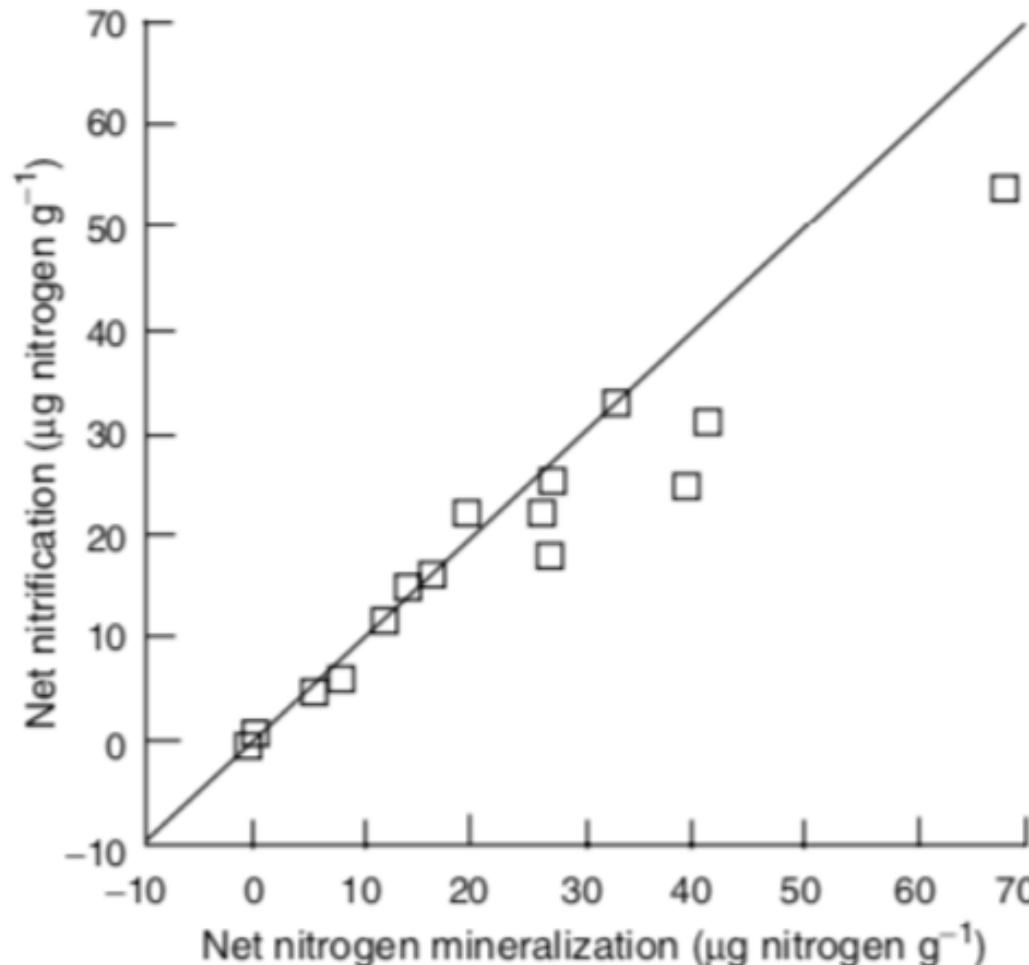
Constantly happening in soil and determined by the amount of NH_3 produced by mineralization

Nitrification: $\text{NH}_3 \rightarrow \text{NO}_2 \rightarrow \text{NO}_3$



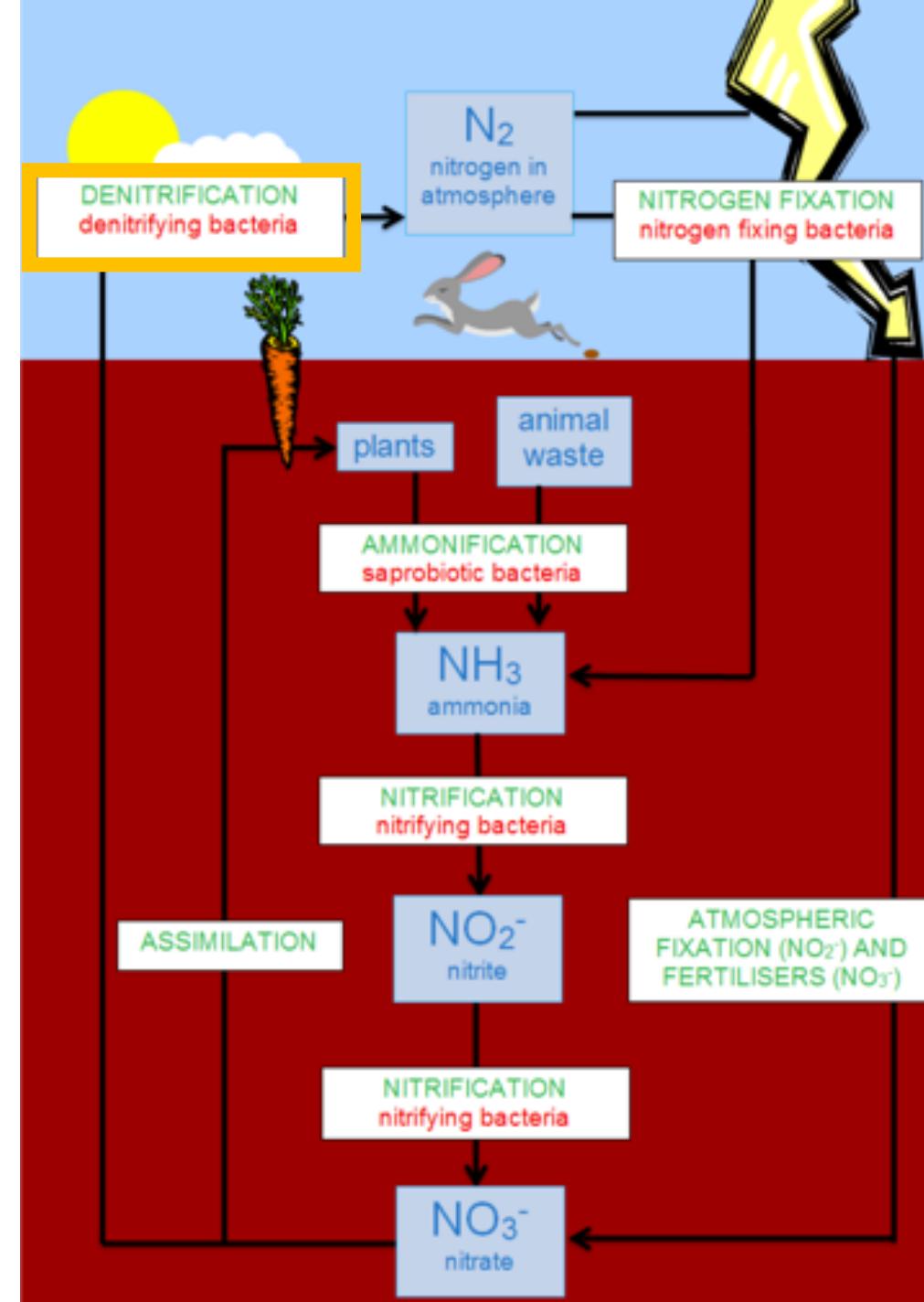
NH₃ amount explains spatial and temporal variability in nitrification

Nitrification: $\text{NH}_3 \rightarrow \text{NO}_2 \rightarrow \text{NO}_3$

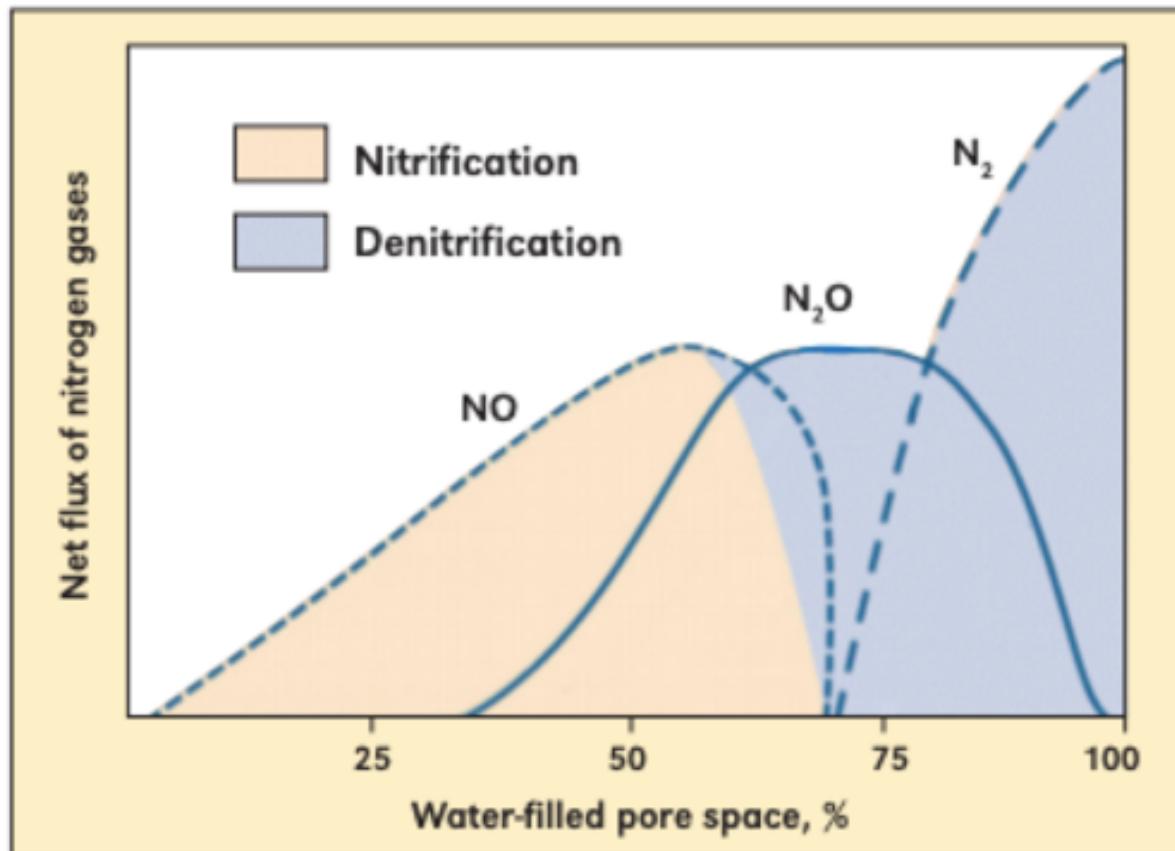


Consequences

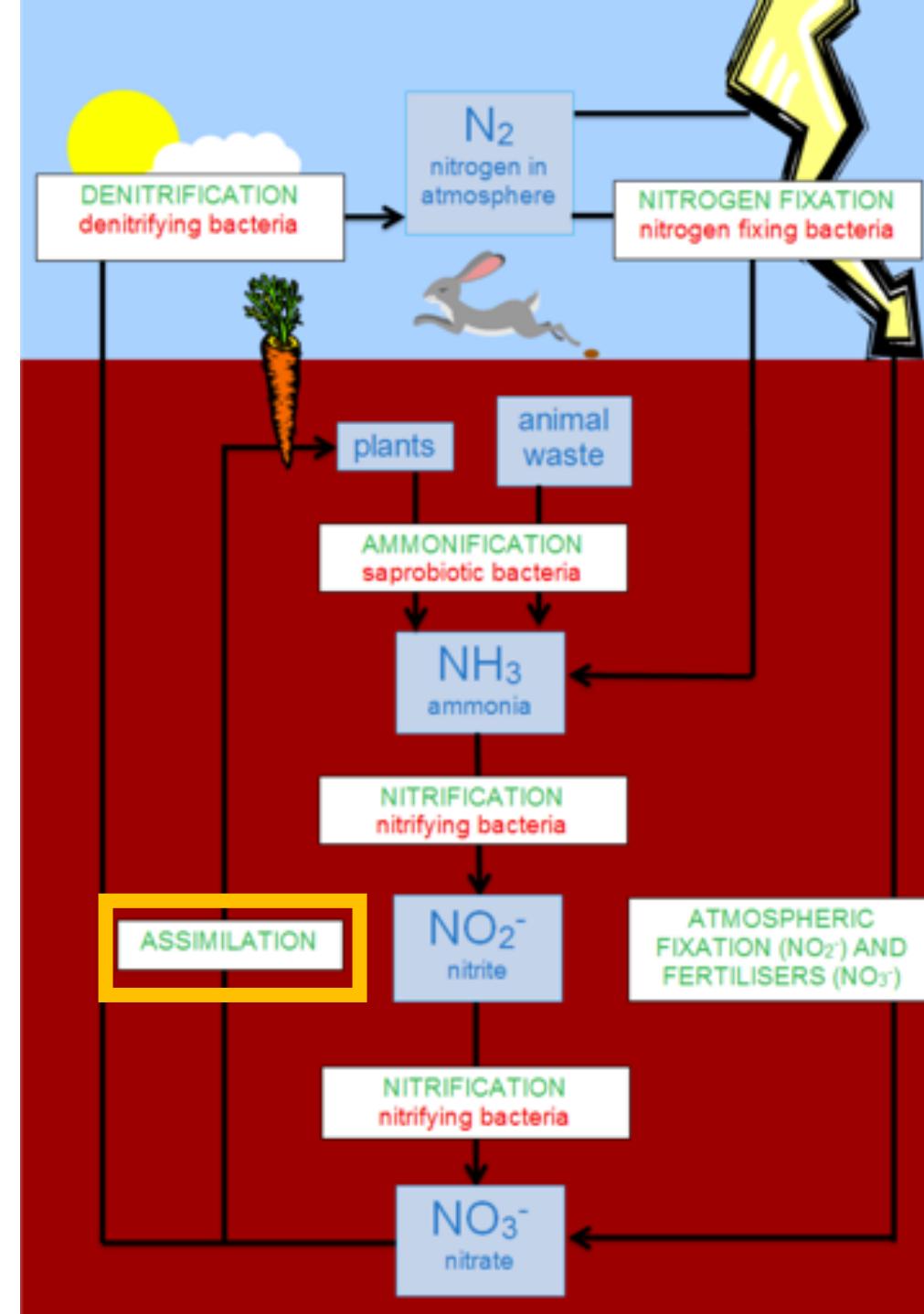
- N gas production
- N more mobile



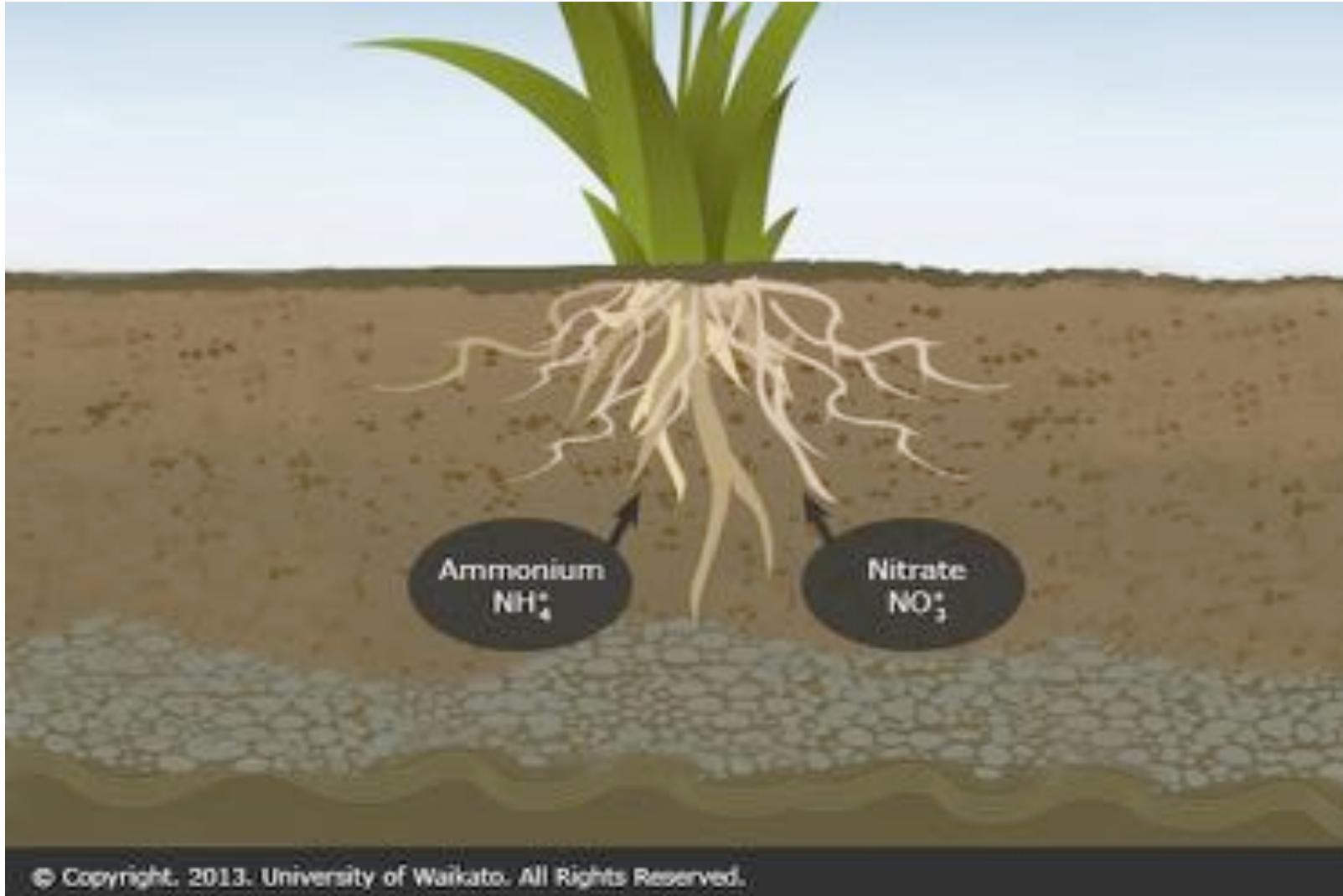
Denitrification: $\text{NO}_3 \rightarrow \text{NO}$, $\text{N}_2\text{O} \rightarrow \text{N}_2$



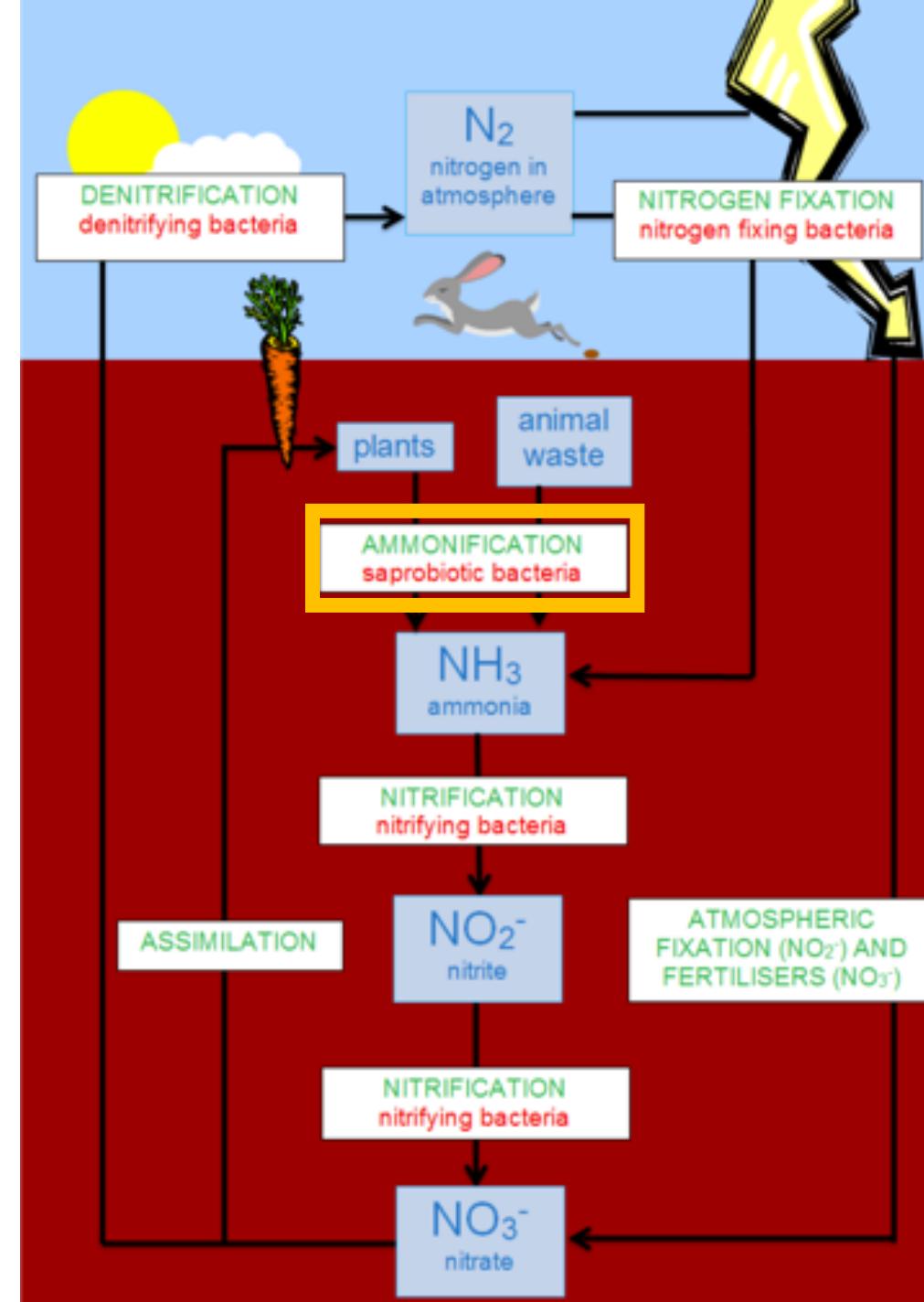
Occurs under high NO_3 and low O_2 conditions (e.g., high soil moisture)



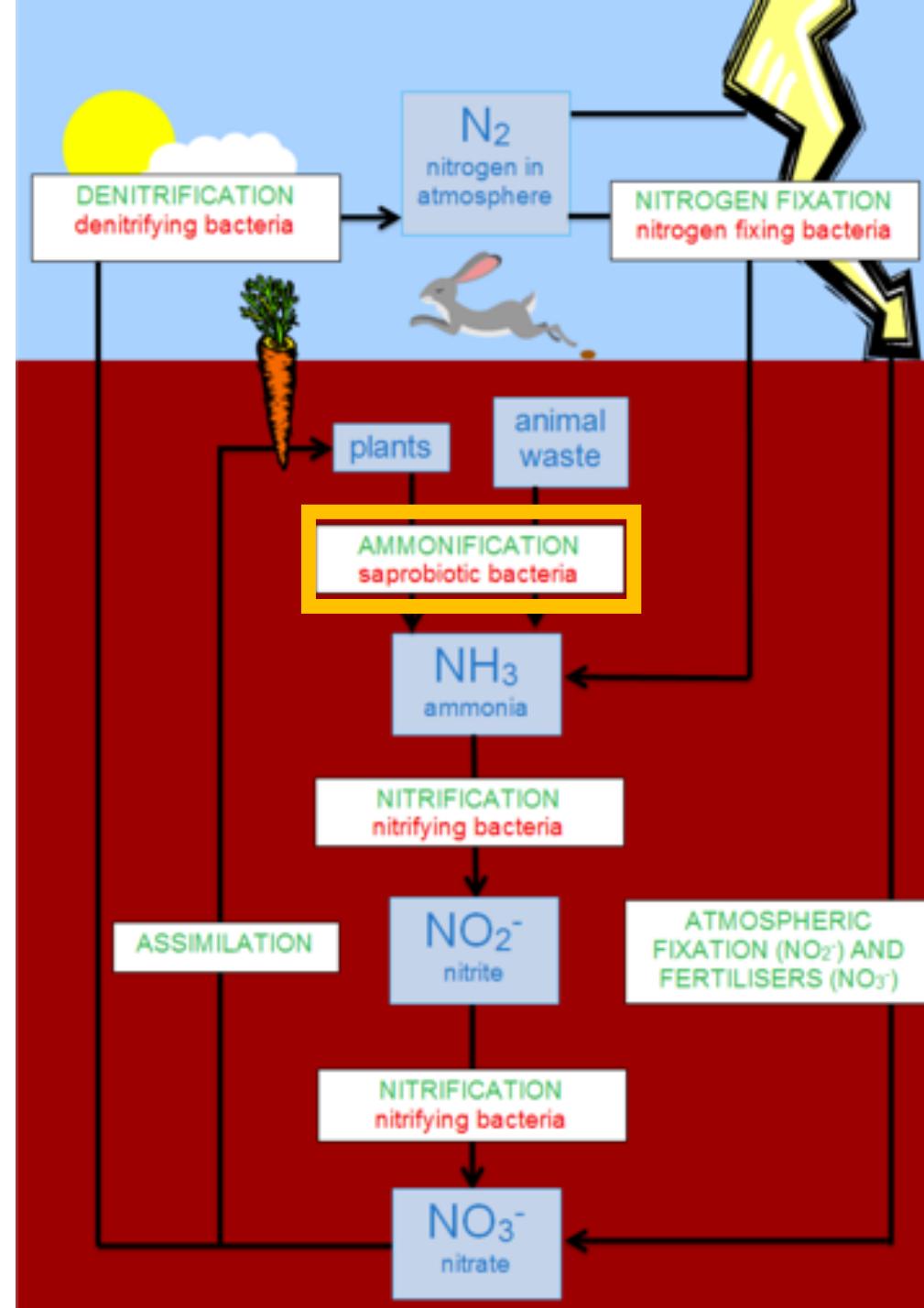
Assimilation: Inorganic N → Organic N



Via microbes or plants

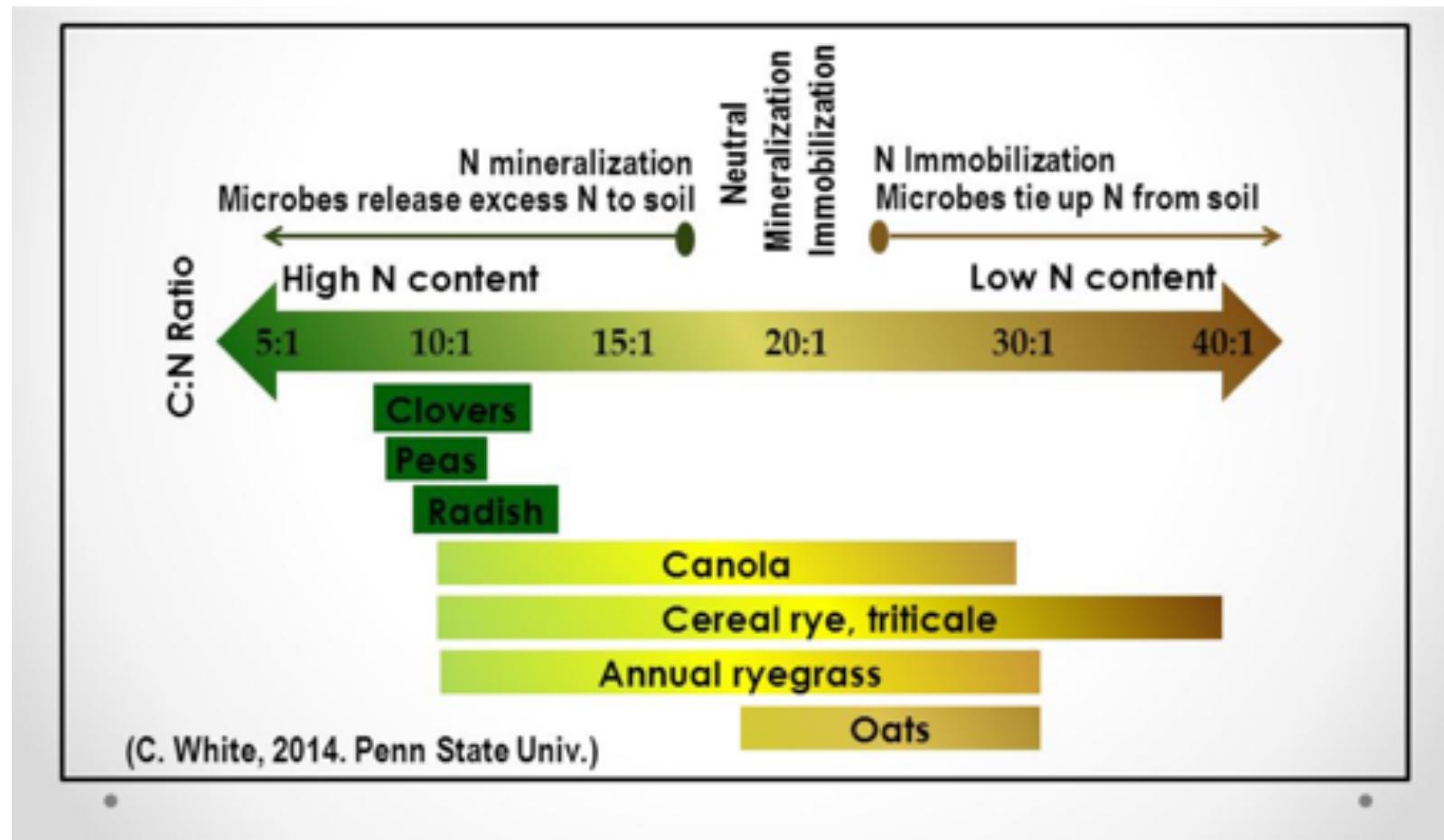


Ammonification +
Nitrification =
Mineralization



Assimilation: Inorganic N → Organic N

Mineralization: Organic N → Inorganic N



Whether you have net mineralization or assimilation depends on the environment

High N = mineralization
Low N = assimilation

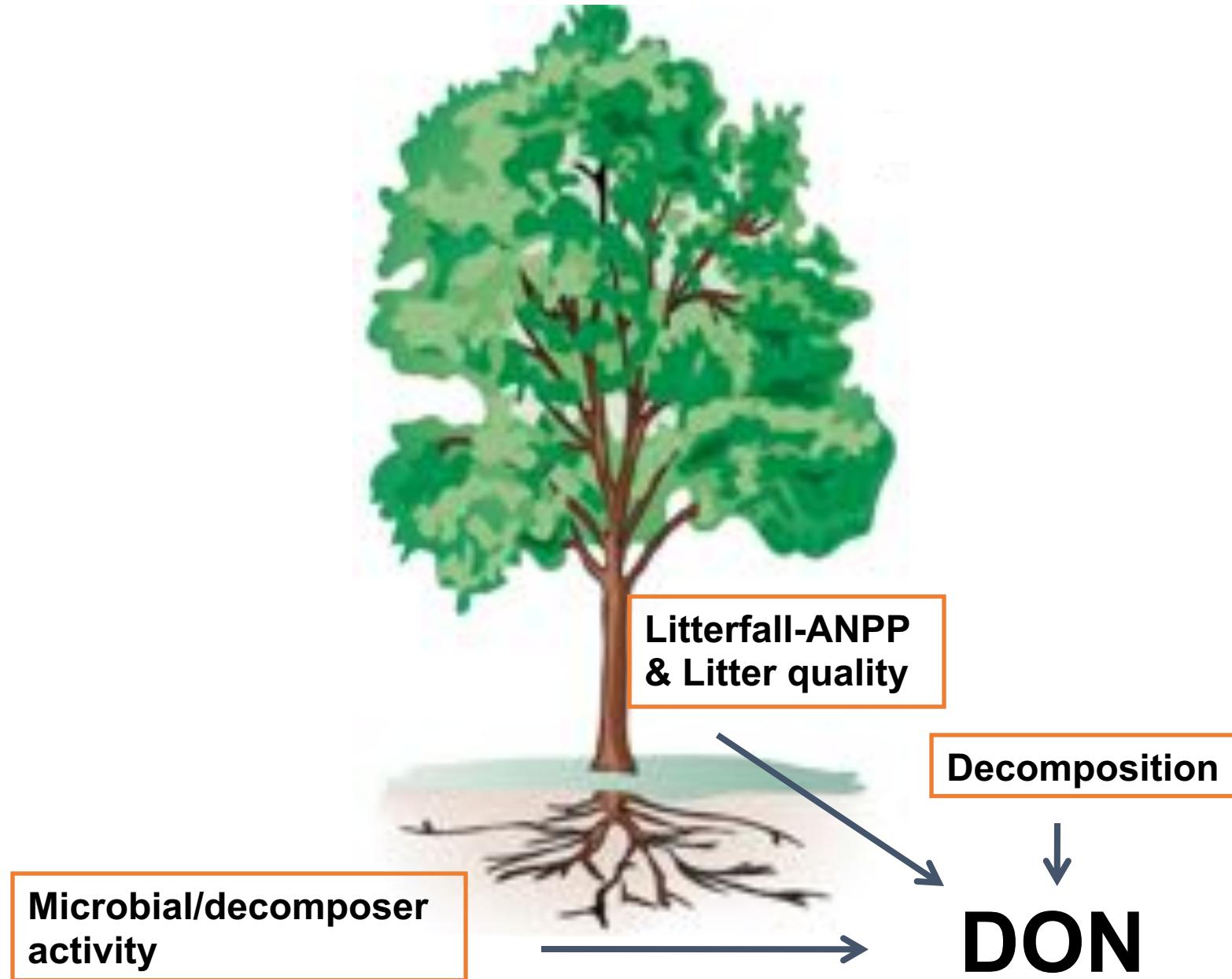
Gross Mineralization = Total amount of N released by mineralization (NH_4^+ and NO_3^-)

Net mineralization = Gross – immobilization – losses (NH_4^+ and NO_3^-)

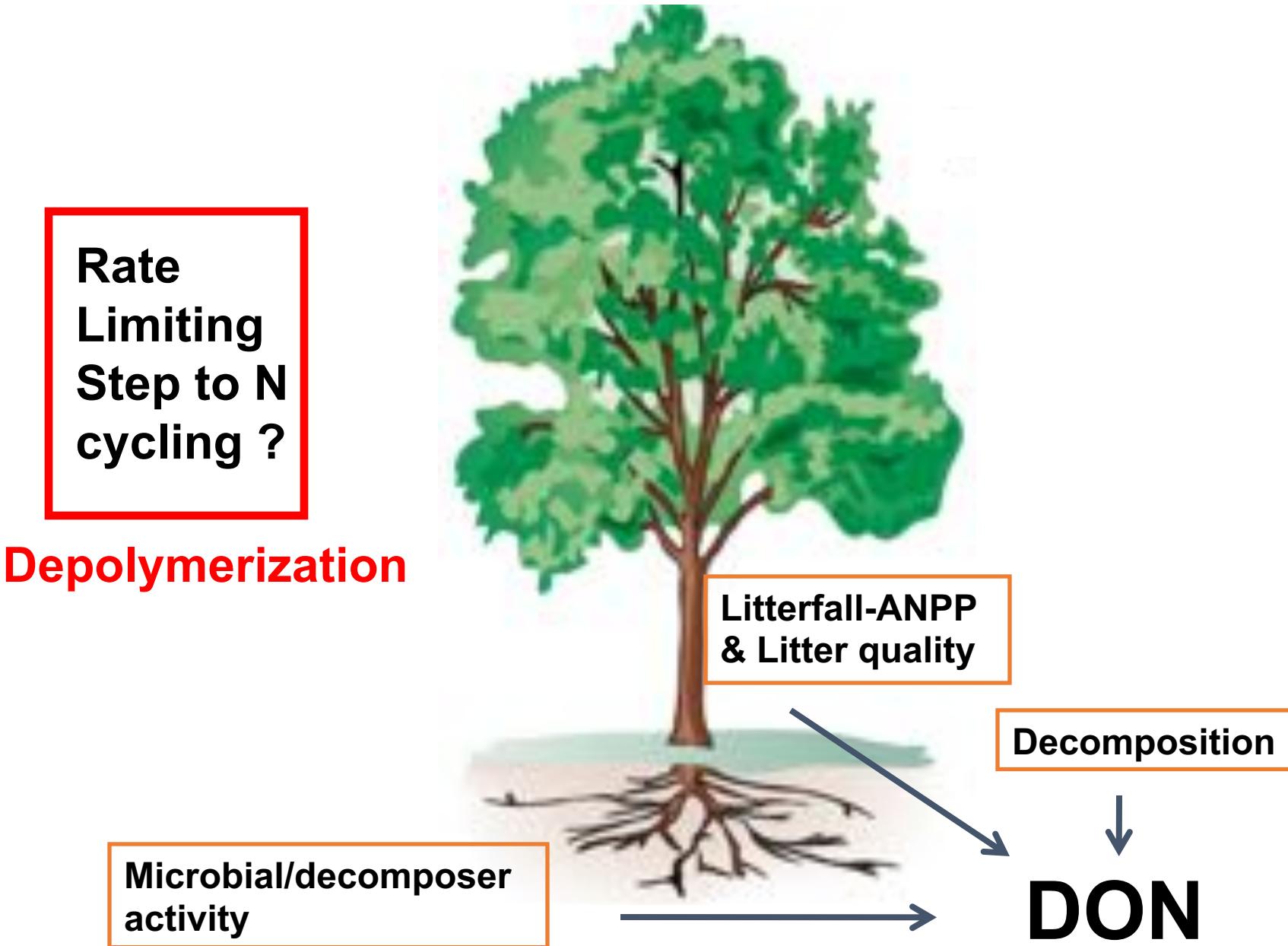
Net mineralization = available for plant uptake

Linking above- and belowground
processes

Linkages between above- and belowground processes

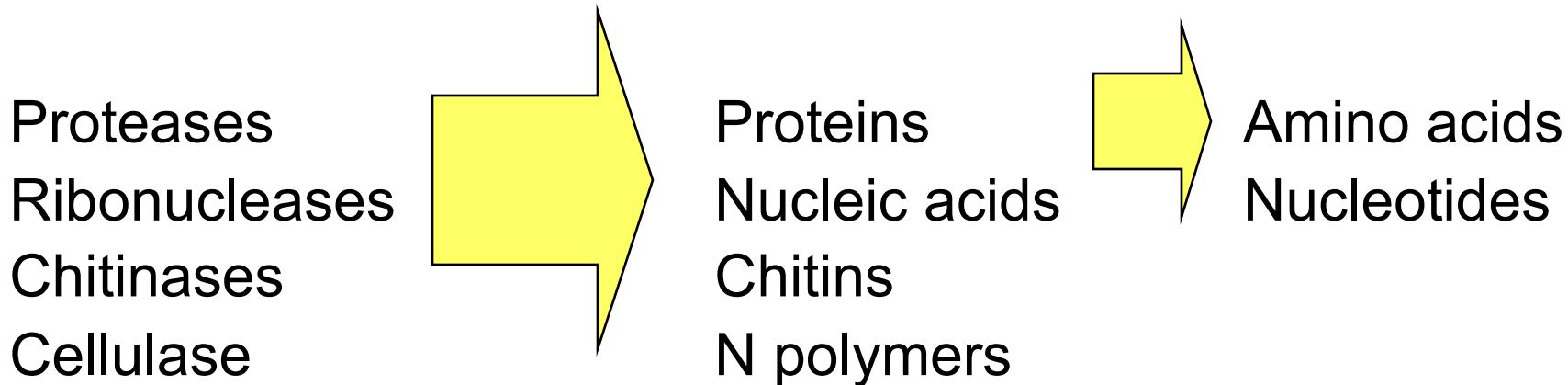


Linkages between above- and belowground processes

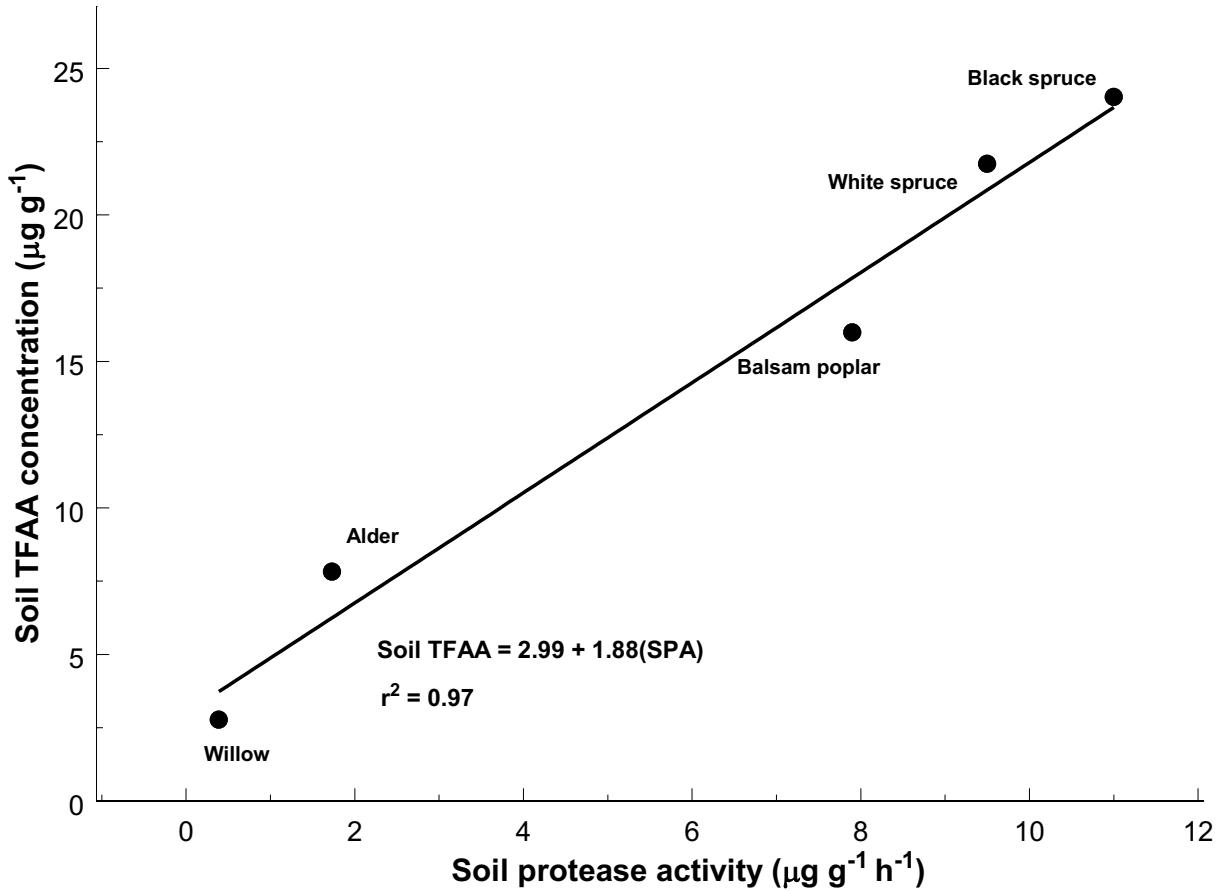


DON

Bacteria and fungi secrete extracellular enzymes to break complex polymers down into water soluble units that can pass through cell membranes



High protease activity yields more amino acids

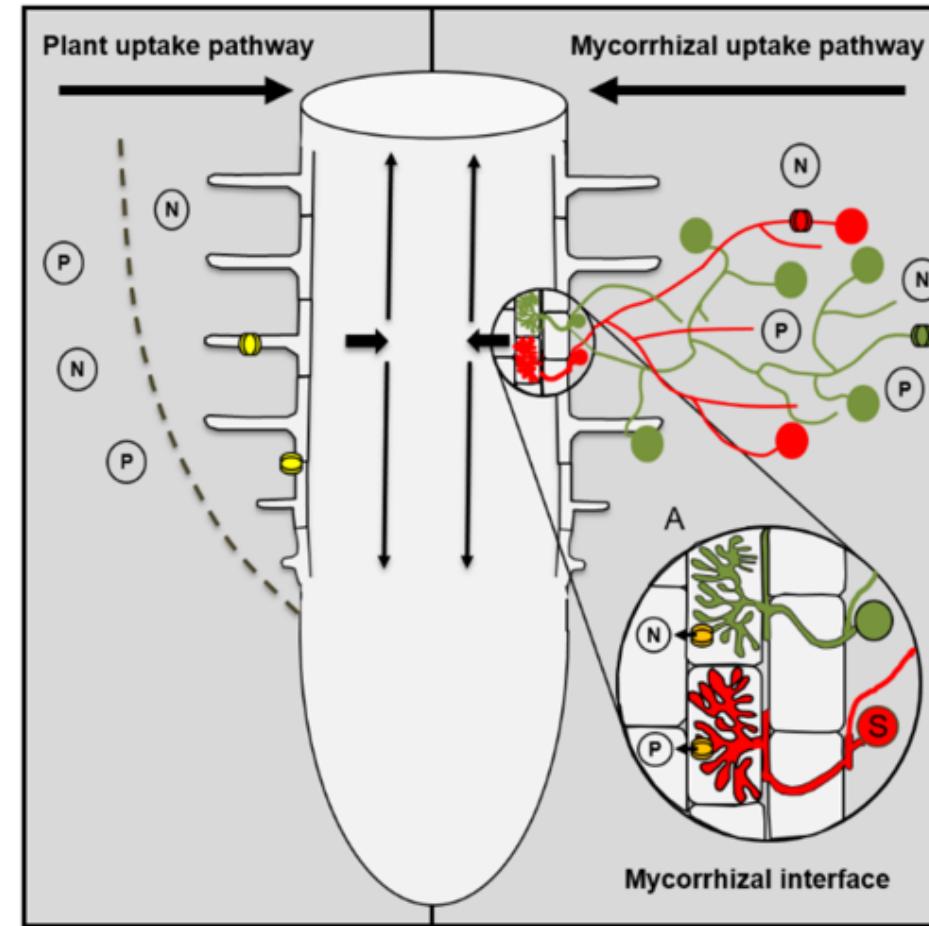


Fate of DON???

Fate of DON

1.Taken up by mycorrhizae

Linkages between above- and belowground processes



Uptake by ECM & plants

Fate of DON

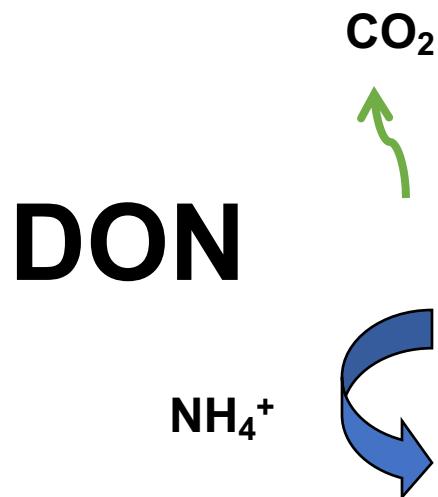
- 1.Taken up by mycorrhizae
- 2.Mineralized by microbes

Nitrogen Mineralization

- N Mineralization results from microbial break-down of DON
- Microbes release NH_4^+ to soil solution as they use carbon



Linkages between above- and belowground processes



Fate of DON

- 1.Taken up by mycorrhizae
- 2.Mineralized by microbes
- 3.Leached (not too common)

Fate of NH₄⁺???

Fate of NH_4^+

1.Nitrified by microbes

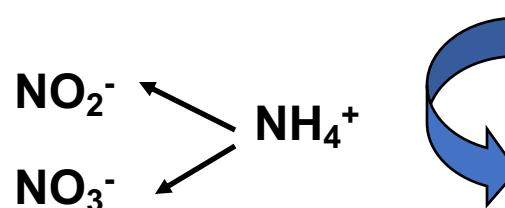
Linkages between above- and belowground processes



Gross Mineralization= Total amount of N released by mineralization (NH_4^+ and NO_3^-)

Net mineralization= Gross – immobilization – losses (NH_4^+ and NO_3^-)
(available for plant uptake)

DON



Nitrification

Ammonification

Mineralization

Fate of NH_4^+

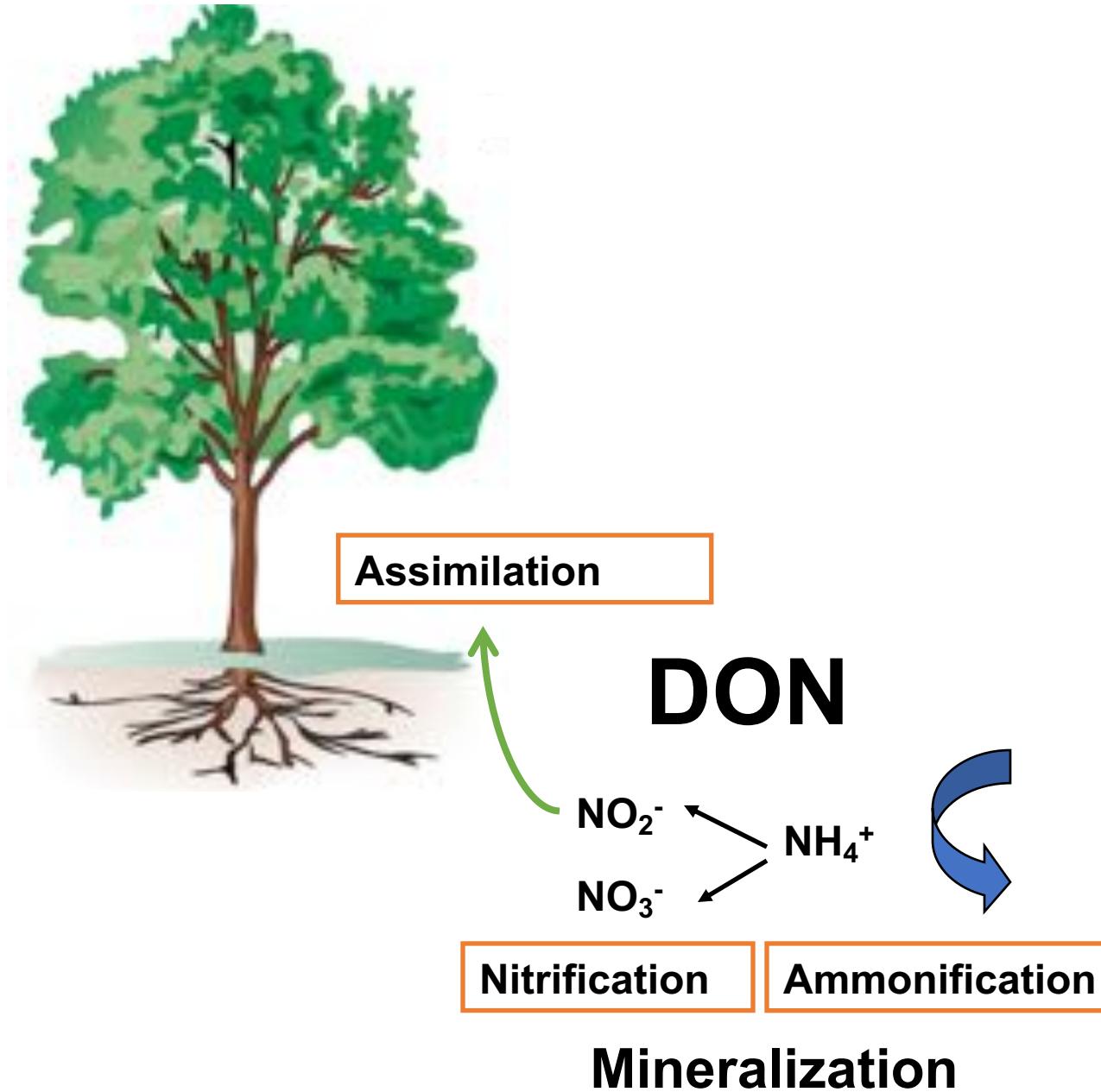
1. Nitrified by microbes
2. Assimilated up by microbes (not too common)
3. Assimilated up by plants (not too common)
4. Leached (not too common)

Fate of NO_3^- ???

Fate of NO_3

1. Assimilated by plants

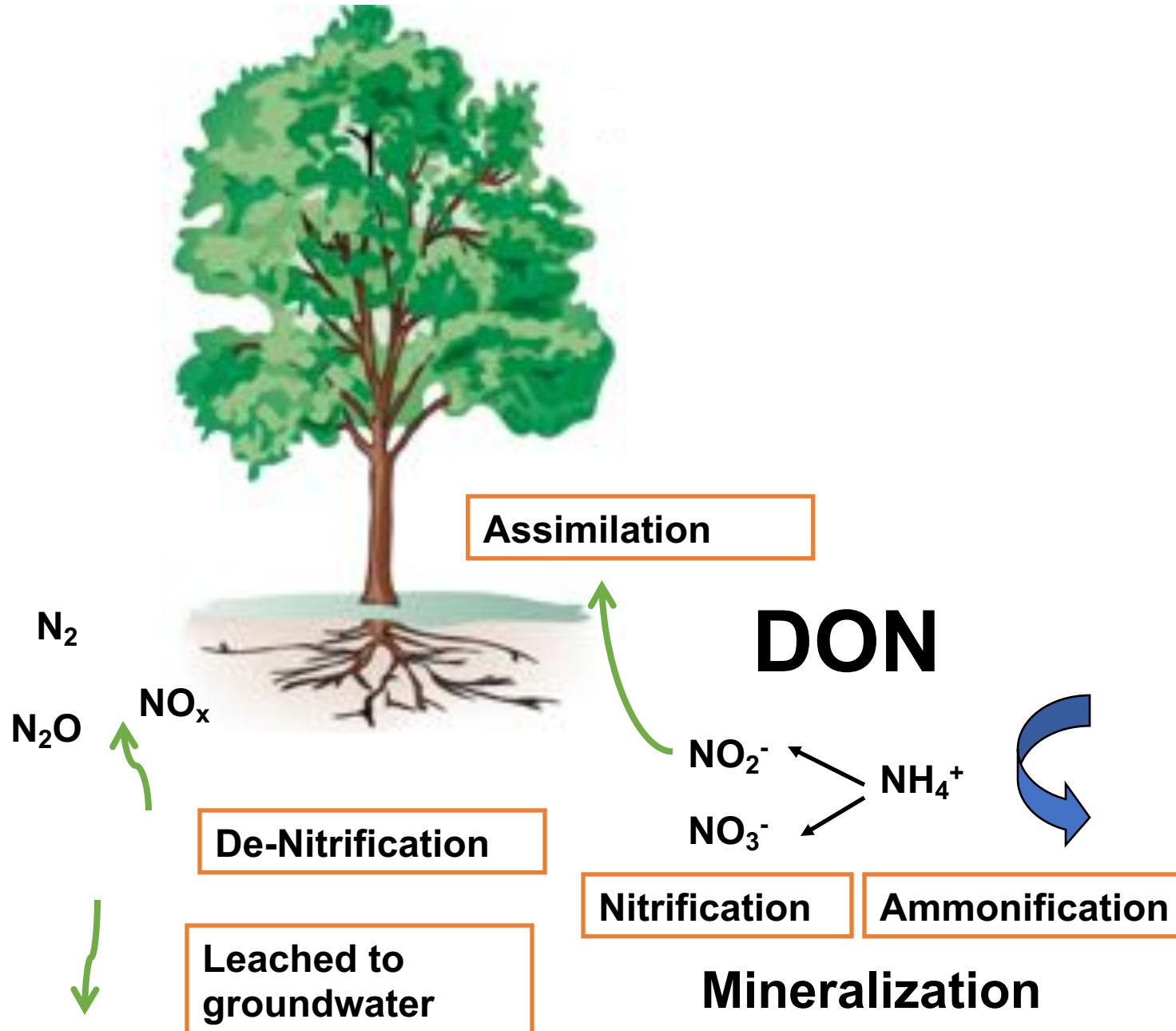
Linkages between above- and belowground processes



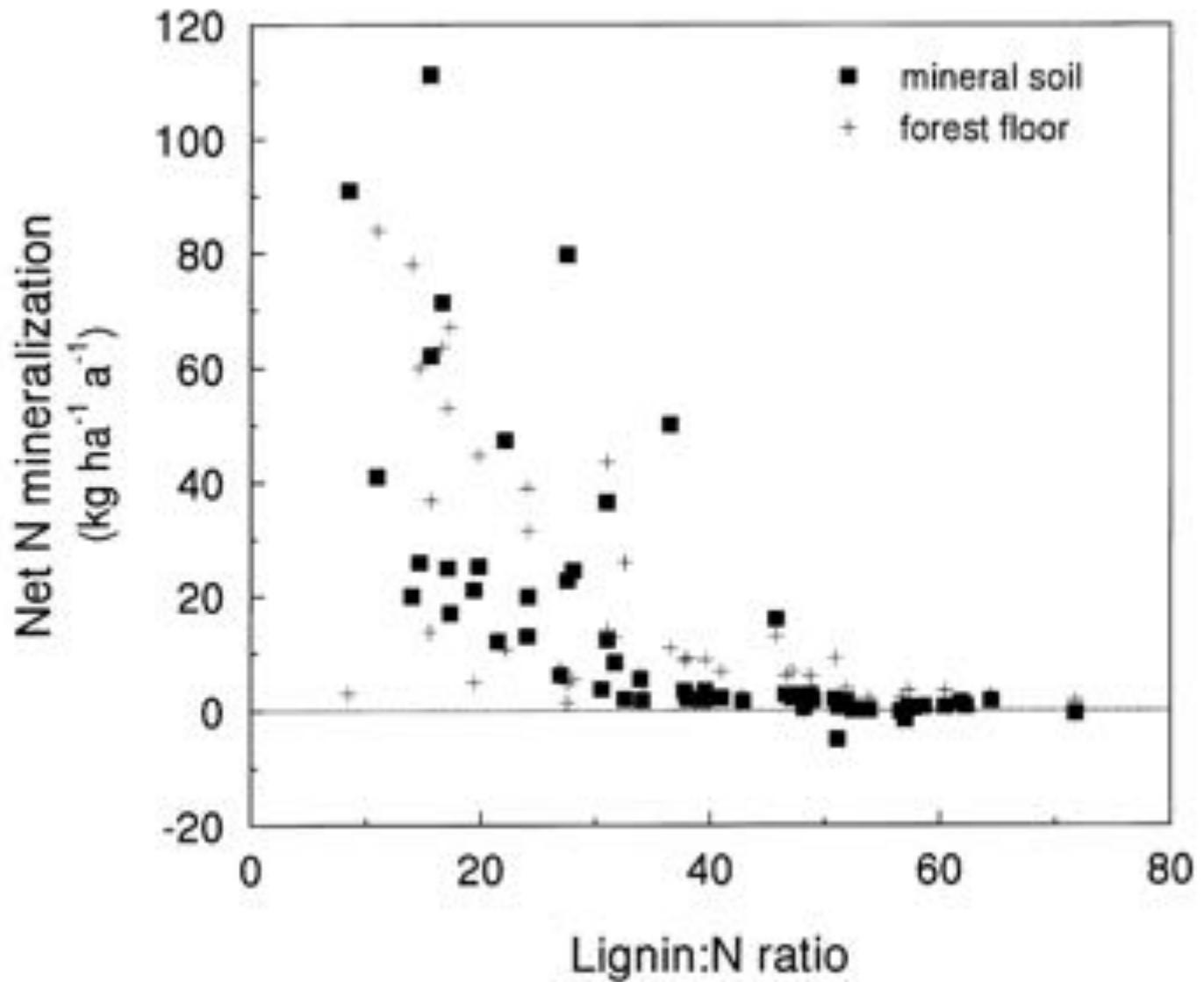
Fate of NO₃

1. Assimilated by plants
2. Denitrified by microbes
3. Leached

Linkages between above- and belowground processes

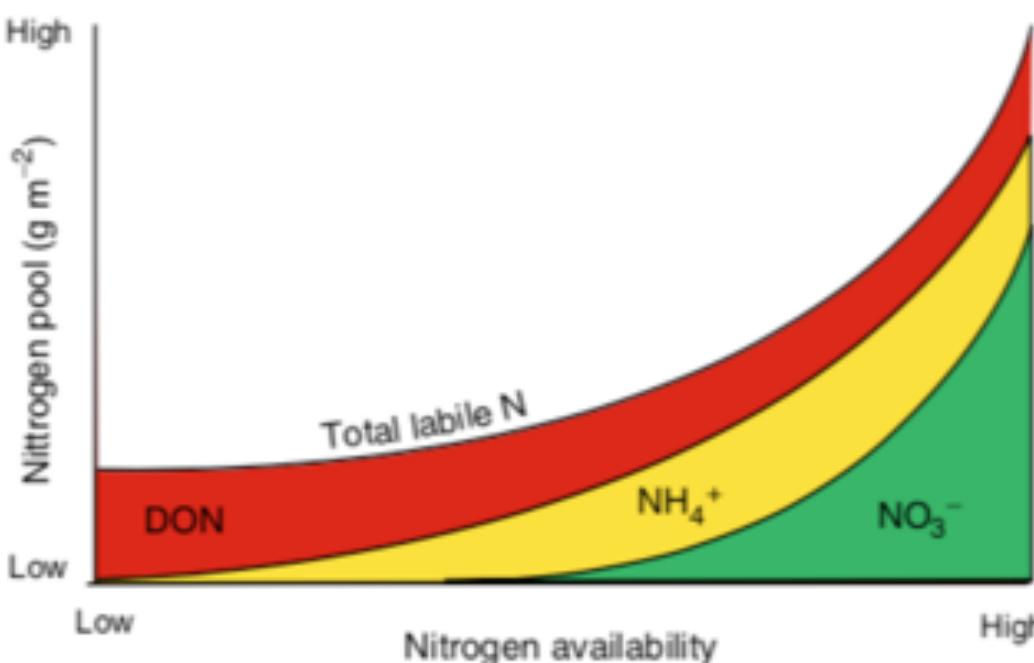
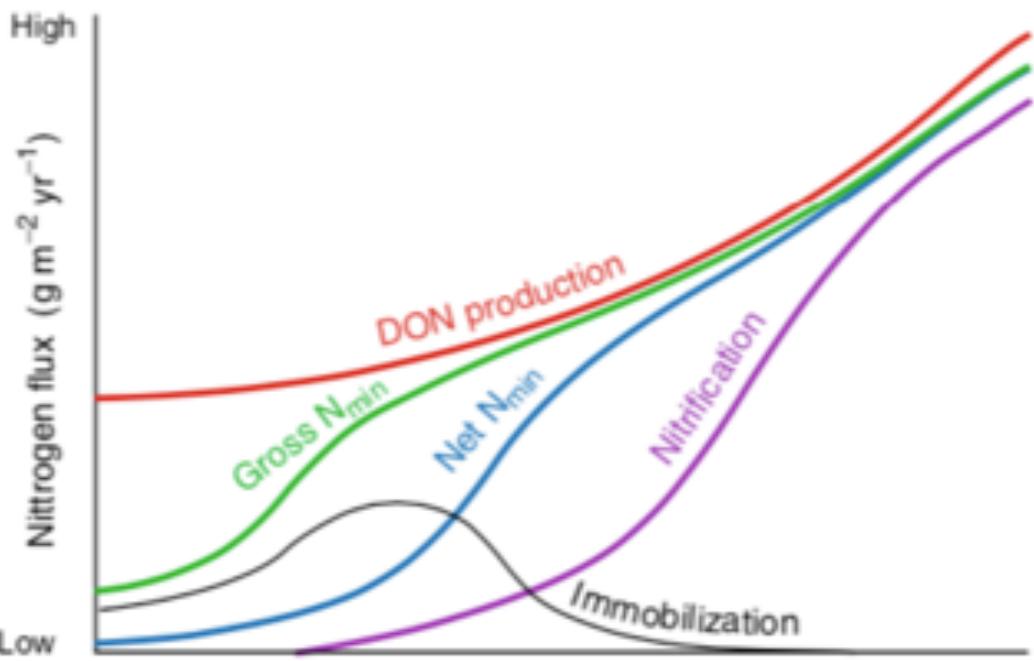


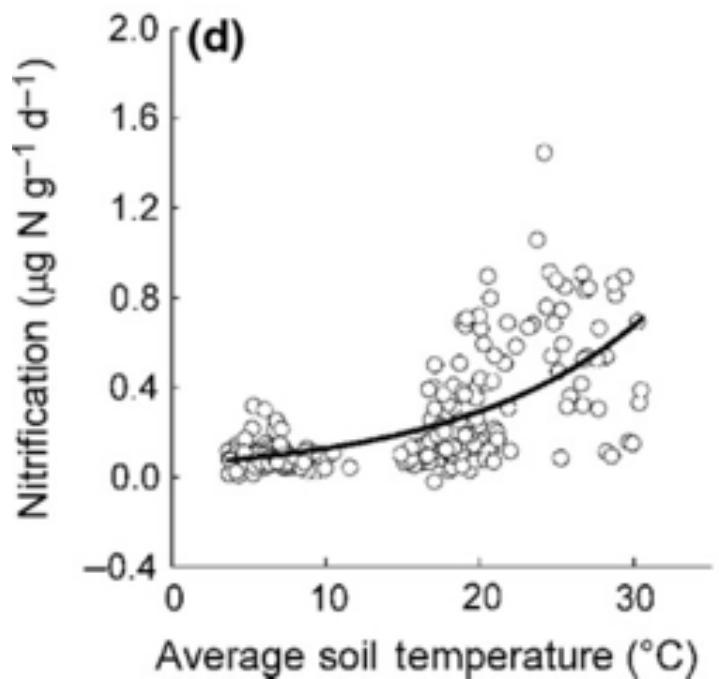
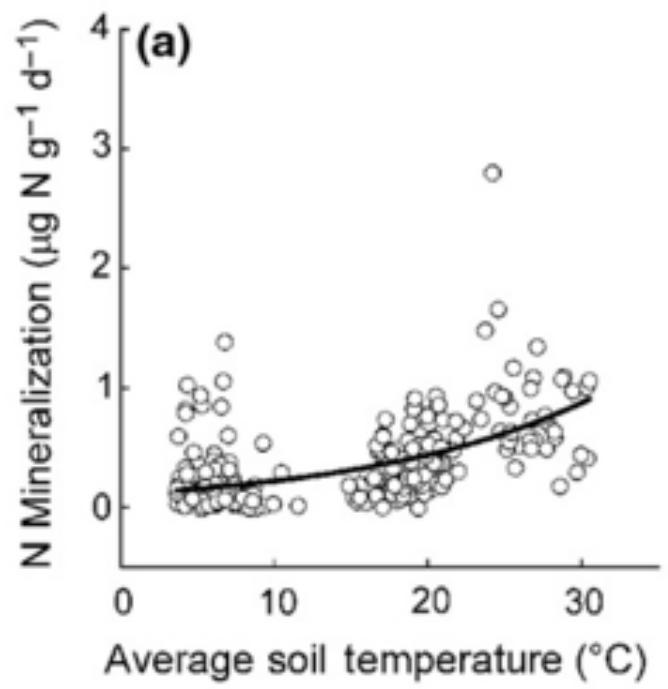
Speed of N cycling



Litter quality
increases N
cycling

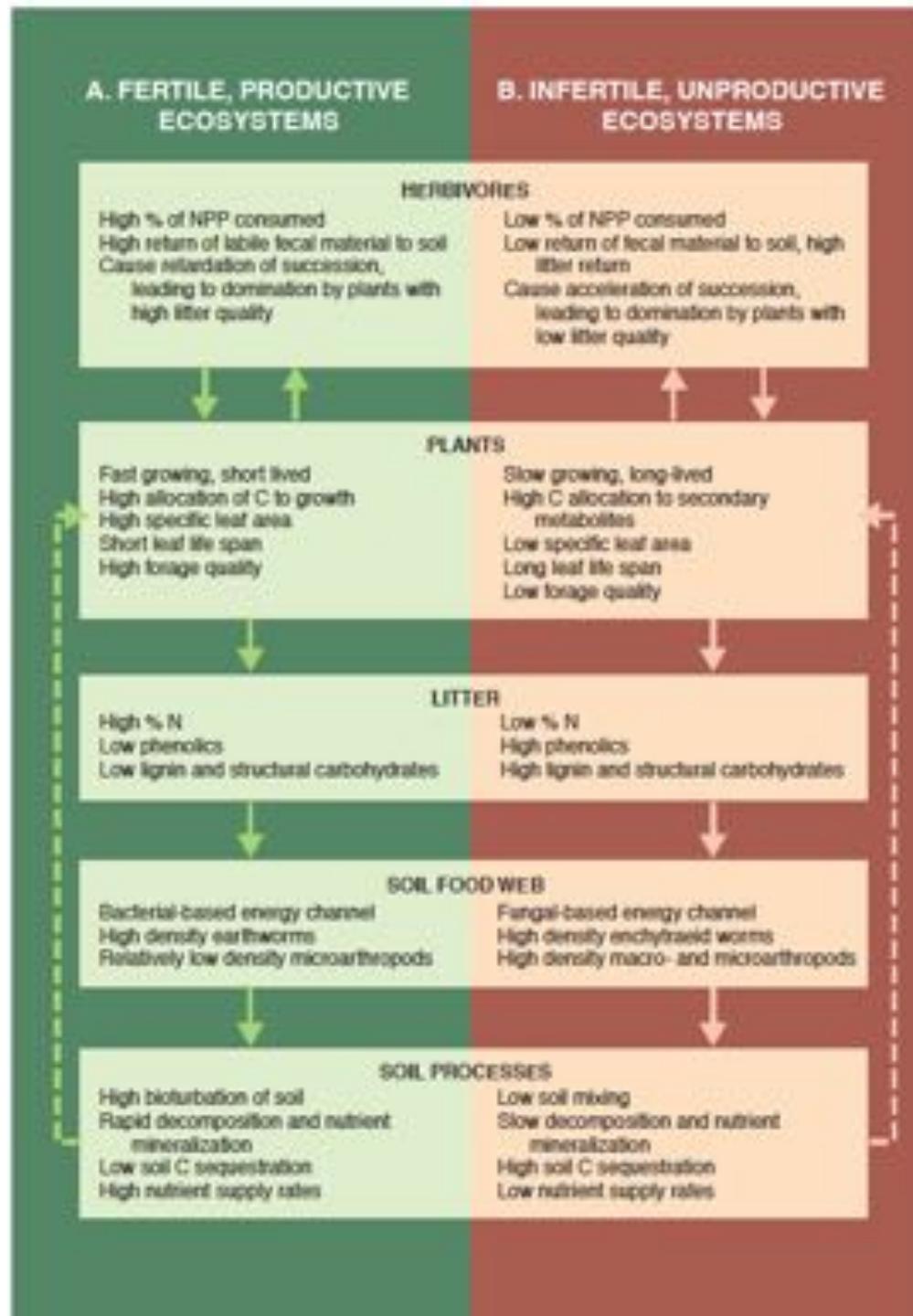
Fig. 9.7 Effect of nitrogen availability on the pools and fluxes of major forms of available nitrogen (dissolved organic nitrogen [DON], ammonium, and nitrate)





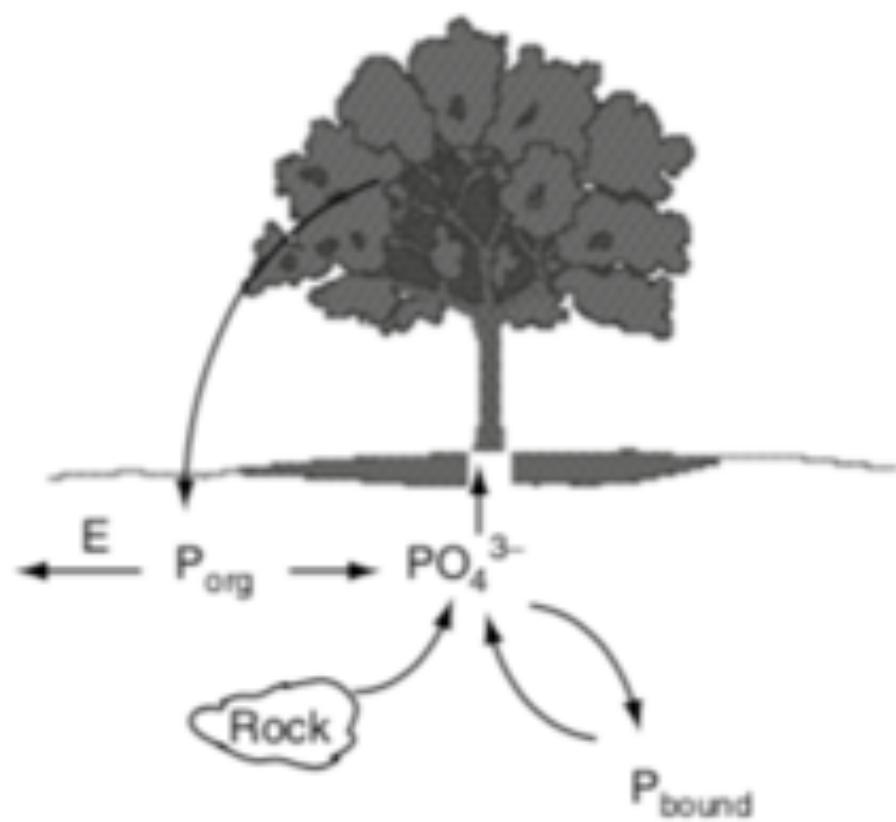
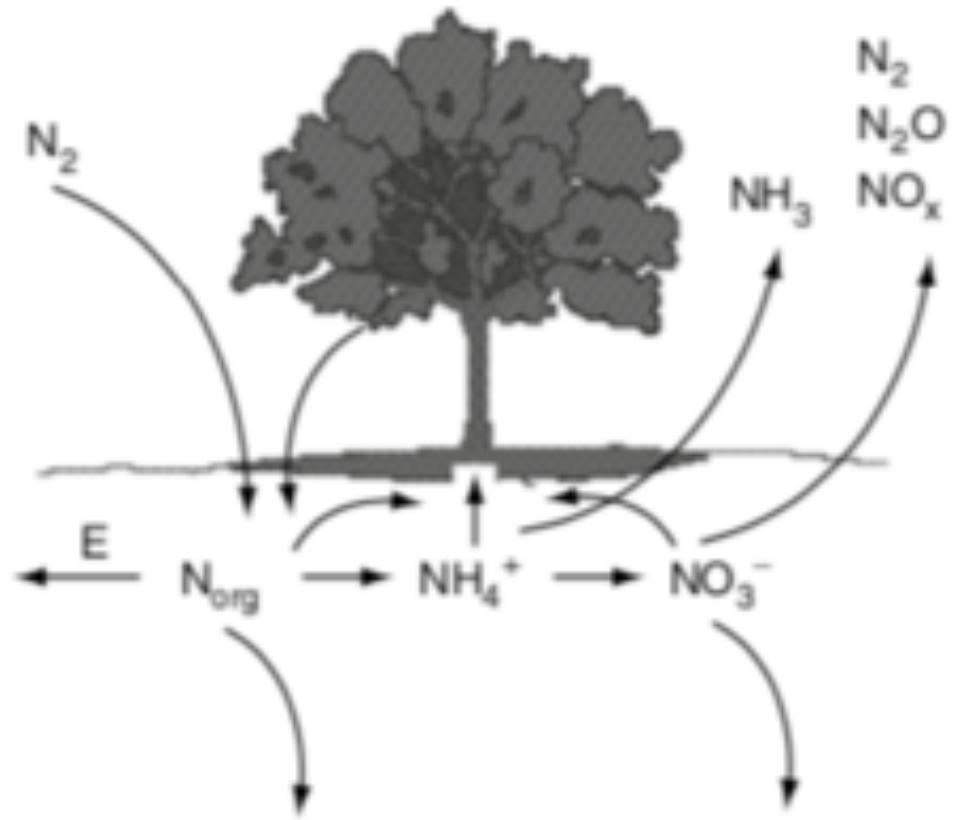
Temperature increases
N cycling

Fast Cycling Systems



Slow Cycling Systems

Why might organisms manipulate
the speed of N cycling?

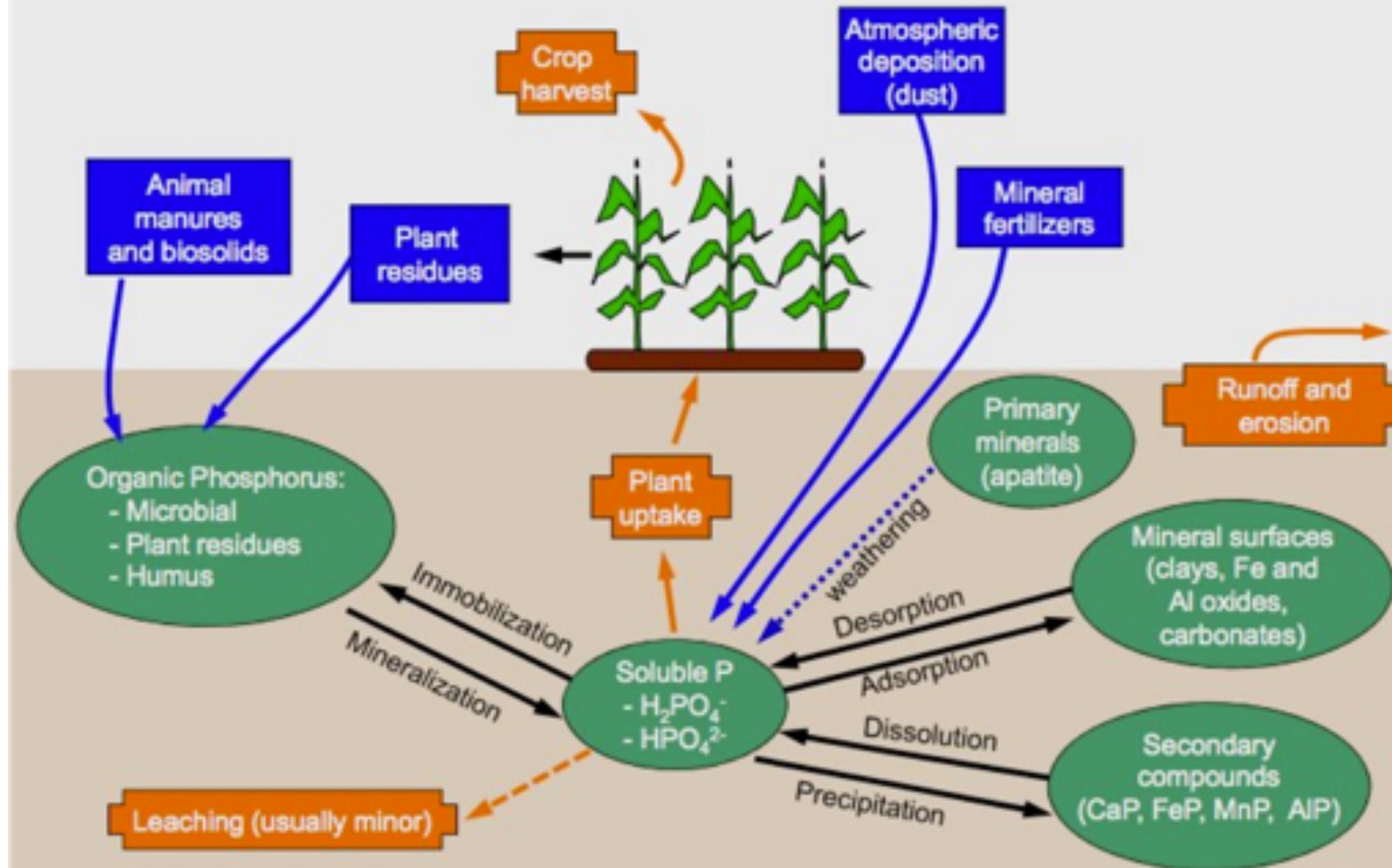


The Phosphorus cycle

Component

Input to soil

Loss from soil

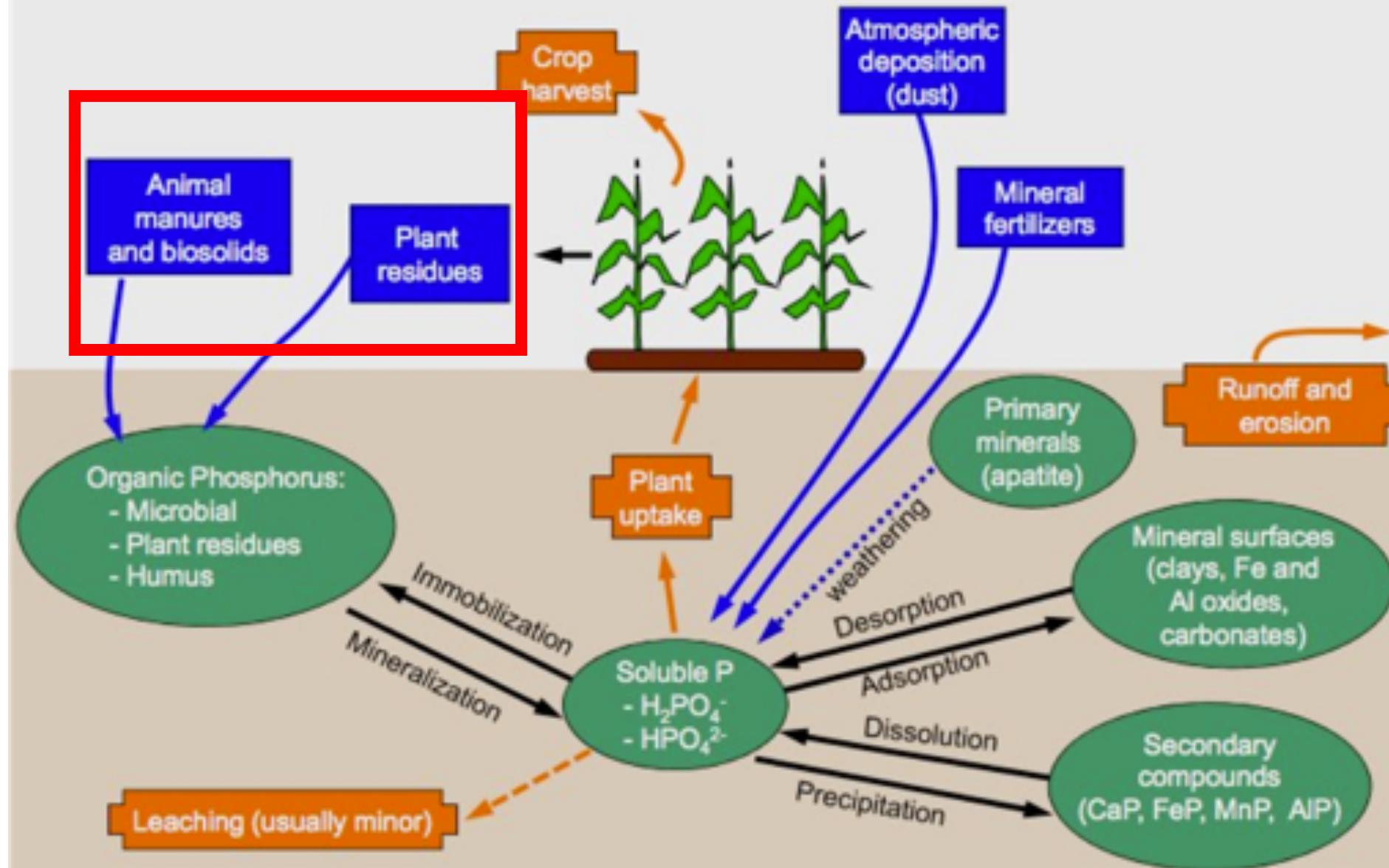


The Phosphorus cycle

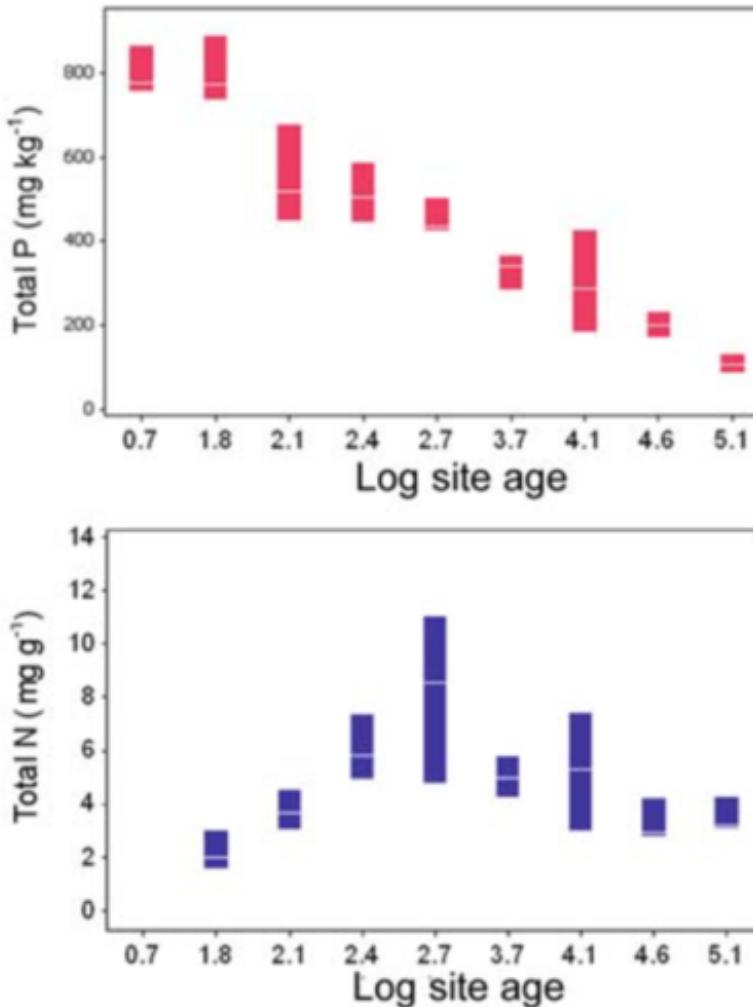
Component

Input to soil

Loss from soil



Most P enters systems through recycling

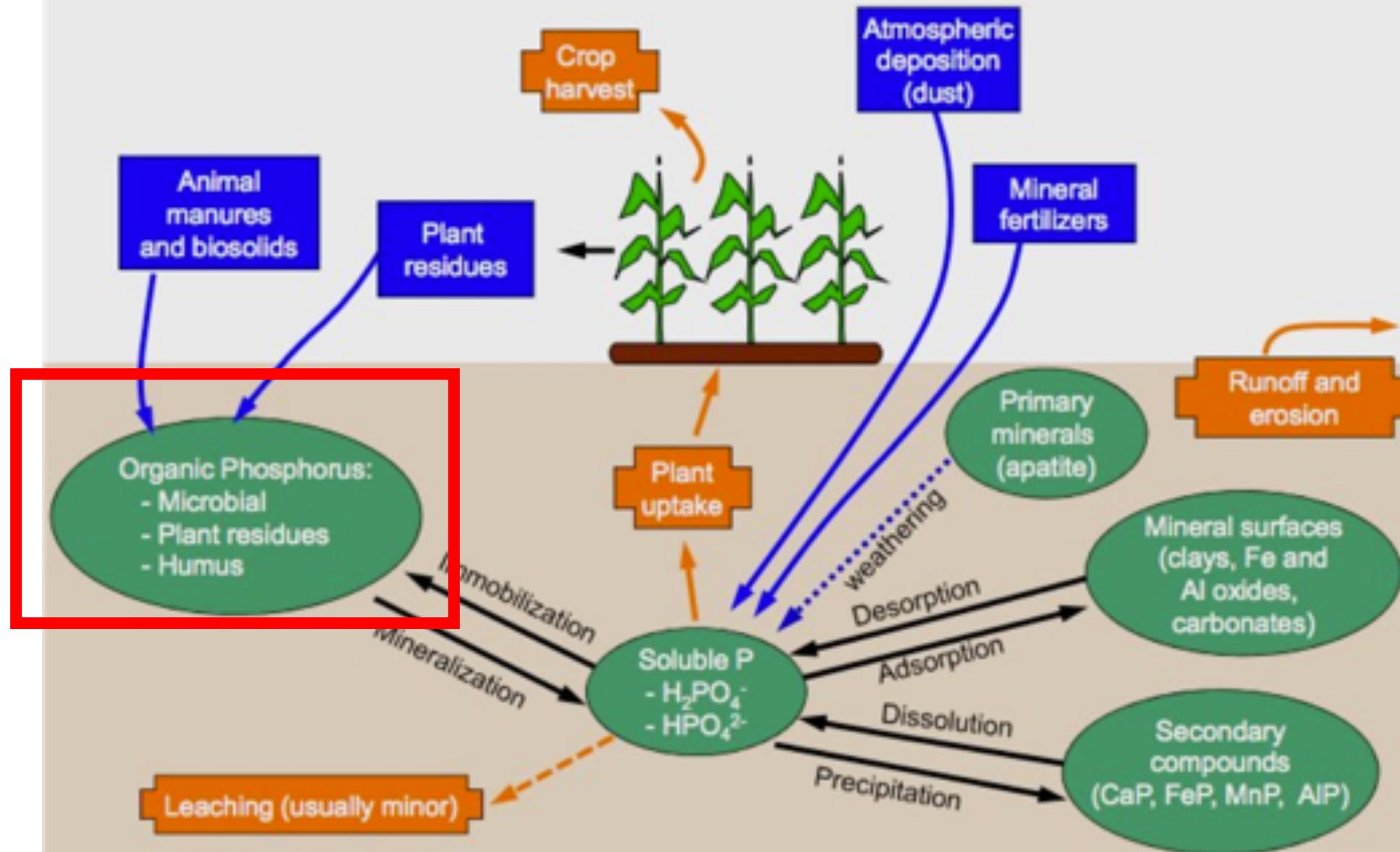


The Phosphorus cycle

Component

Input to soil

Loss from soil



Microbes have a ton of P!

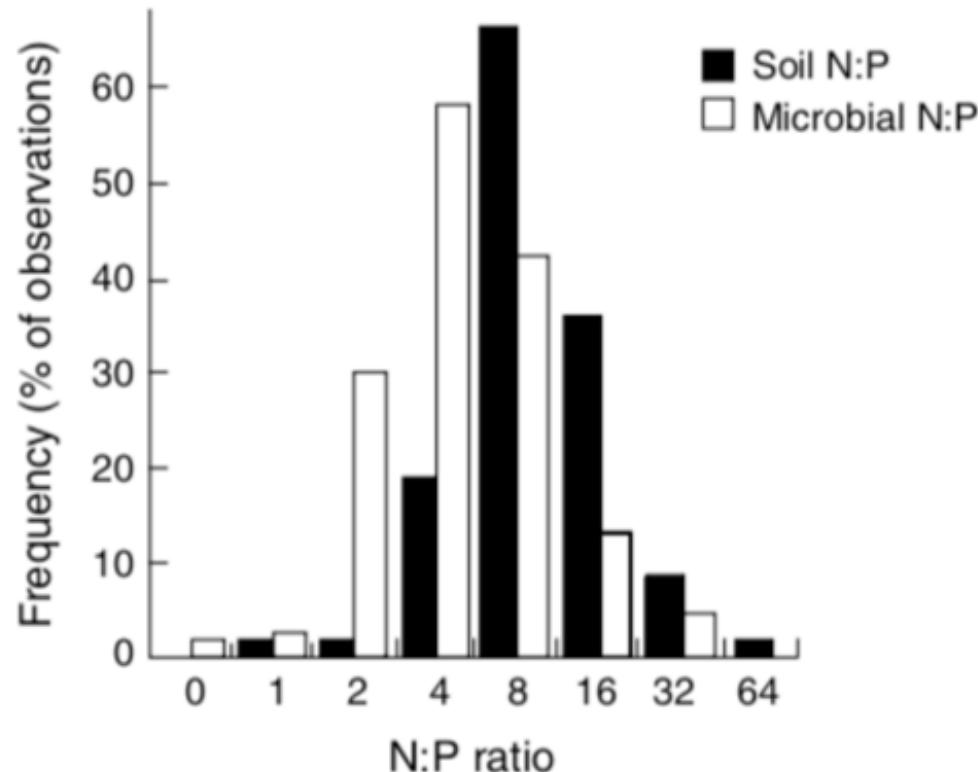
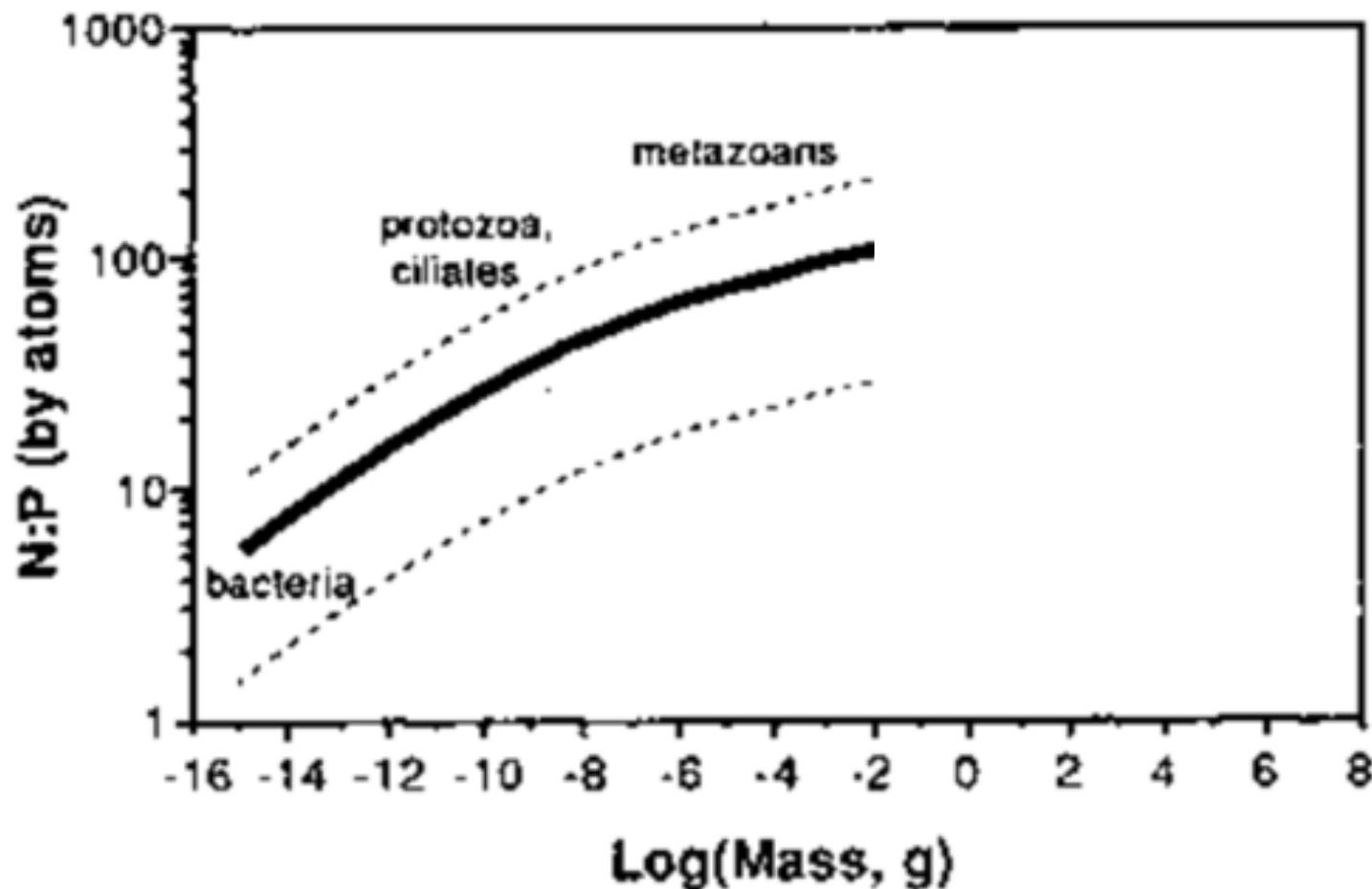


Fig. 9.15 Frequency distribution of N:P ratios in soils and microbial biomass on a \log_2 scale. Redrawn from Cleveland and Liptzin (2007)

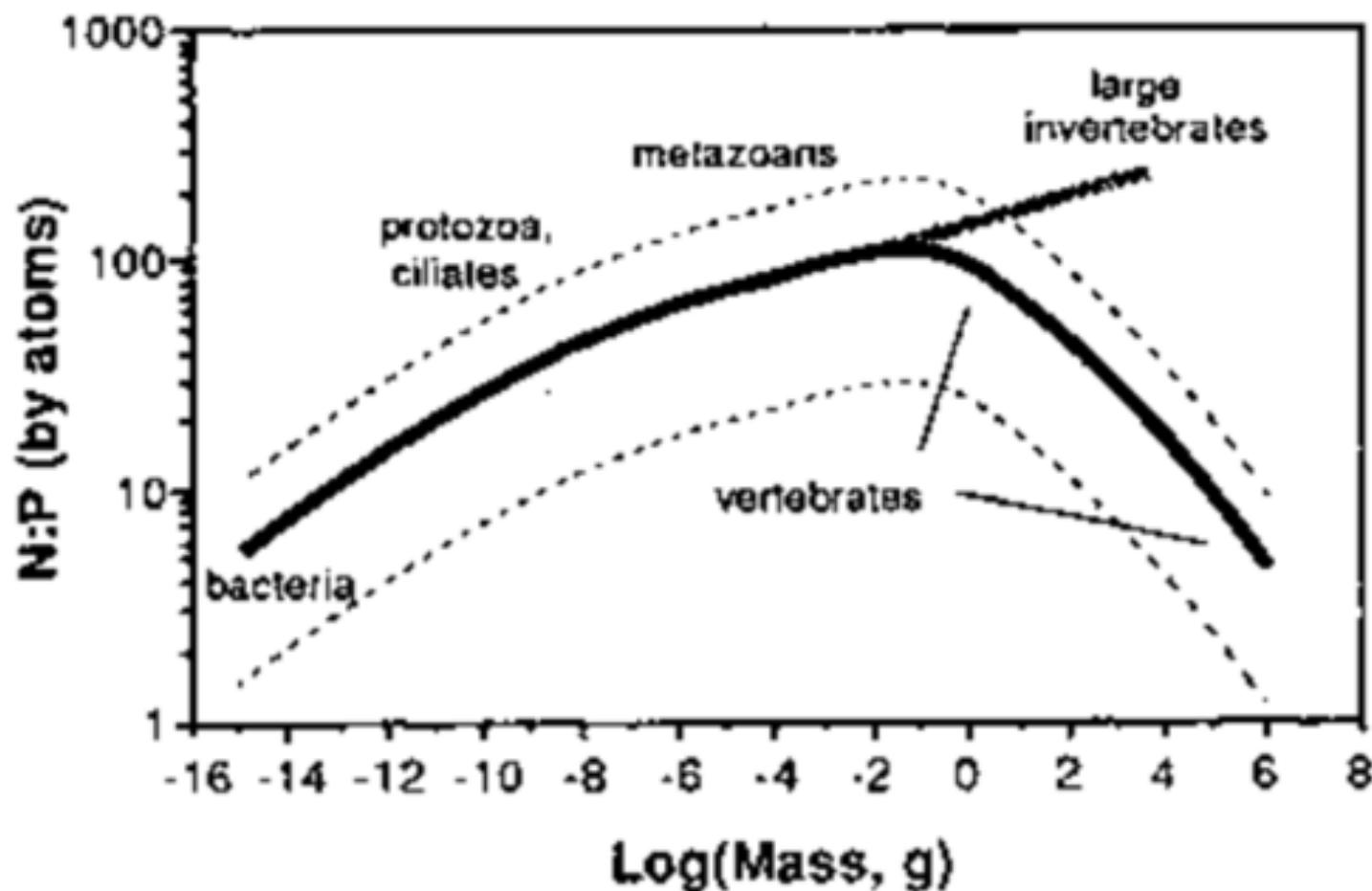
Microbial P = 20-30% total ecosystem P
Microbial N = 4% total ecosystem N
Microbial C = 2% total ecosystem C

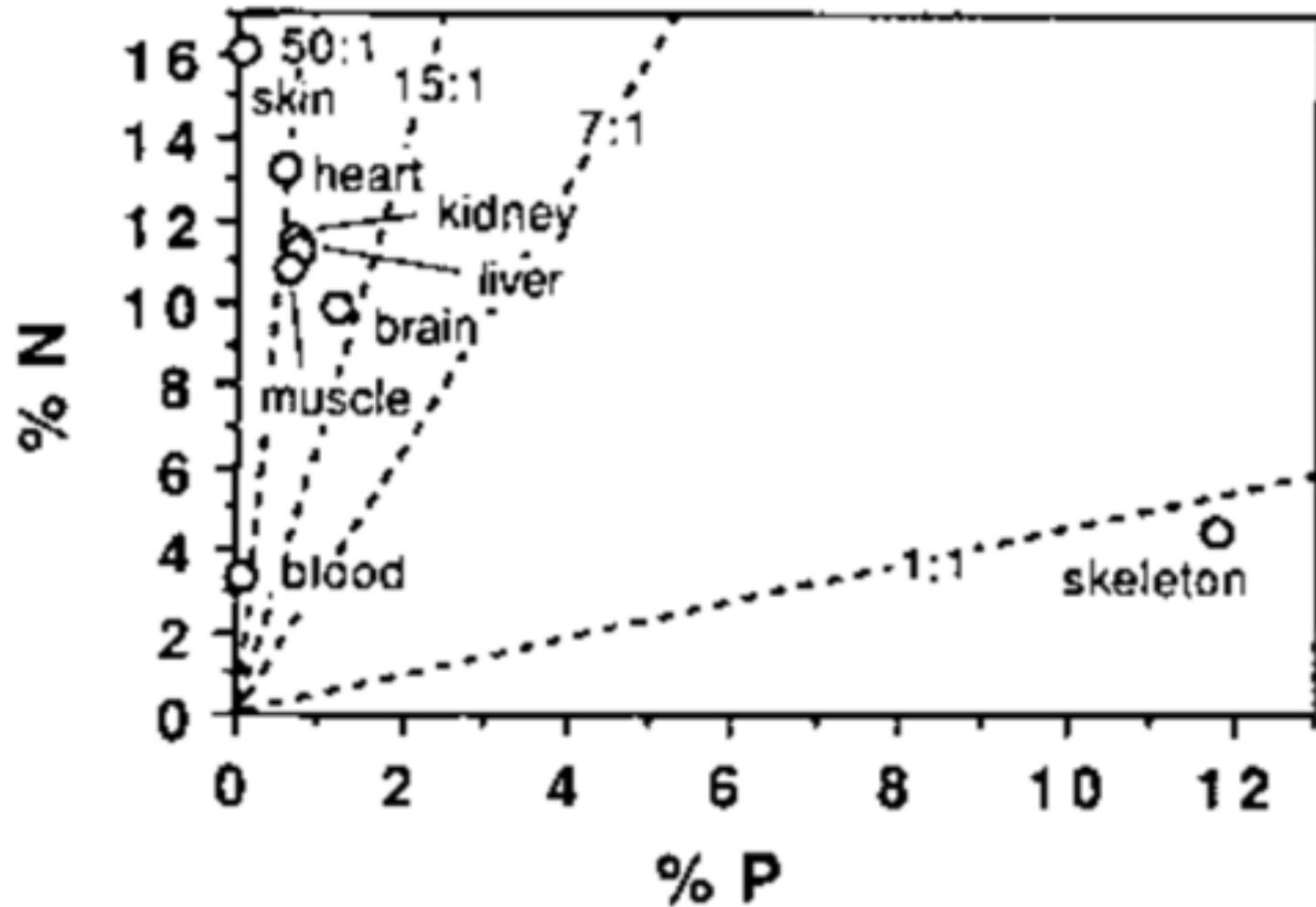
Microbial N:P = 7:1
Plant N:P = 28:1

N:P tends to increase with organism size...



...but vertebrates are weird!



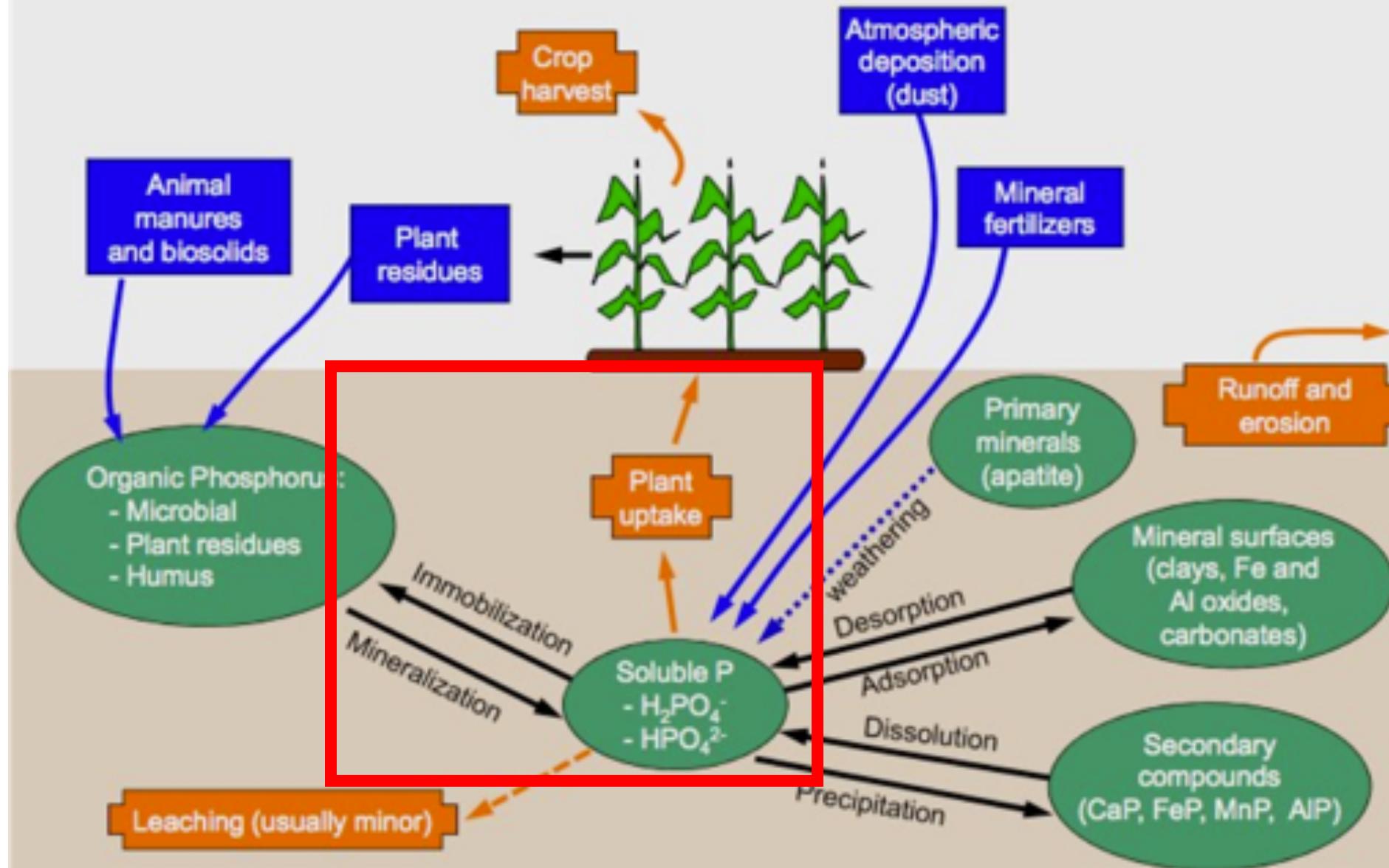


The Phosphorus cycle

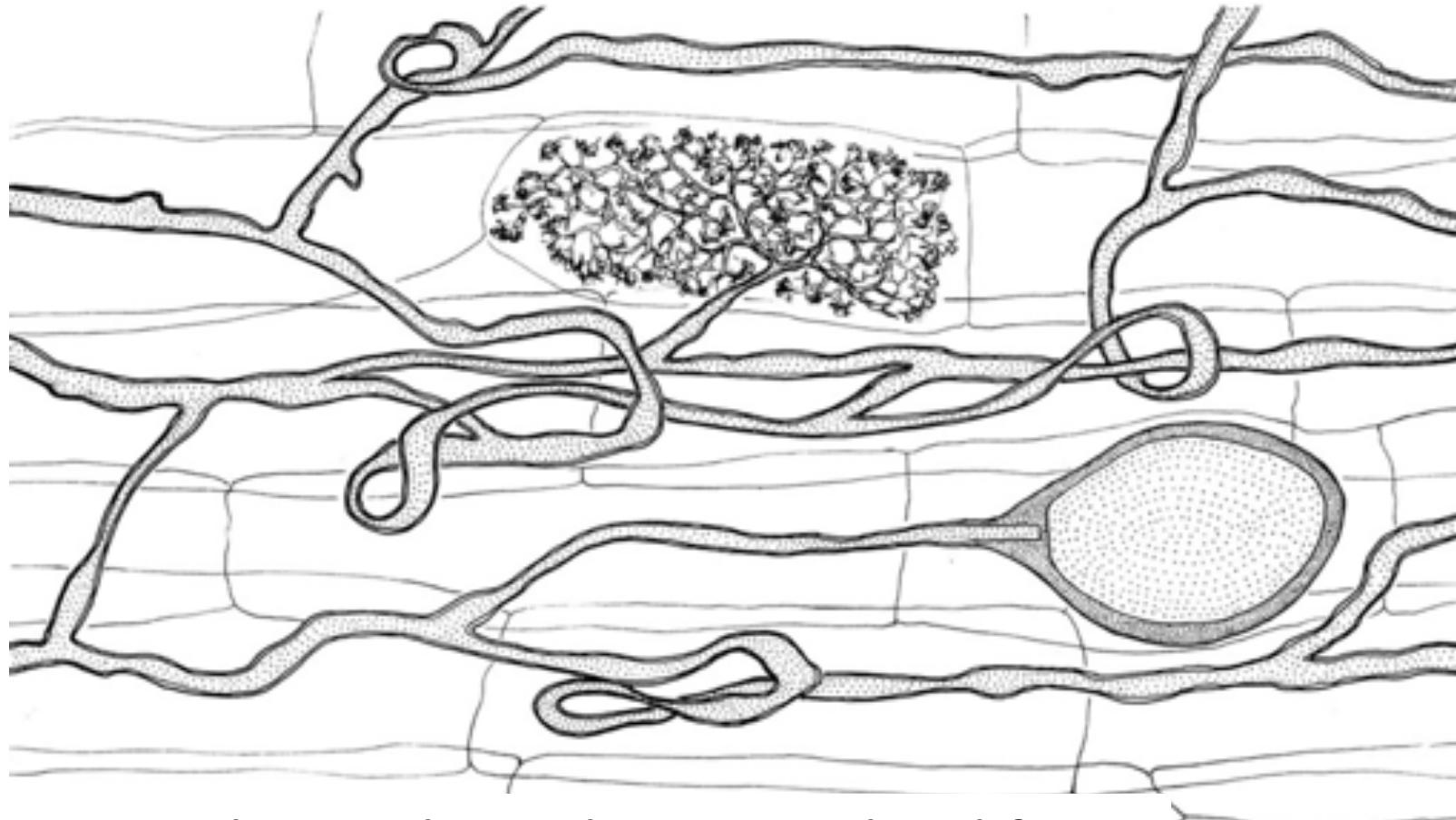
Component

Input to soil

Loss from soil



Mycorrhizae are very important for plant P uptake

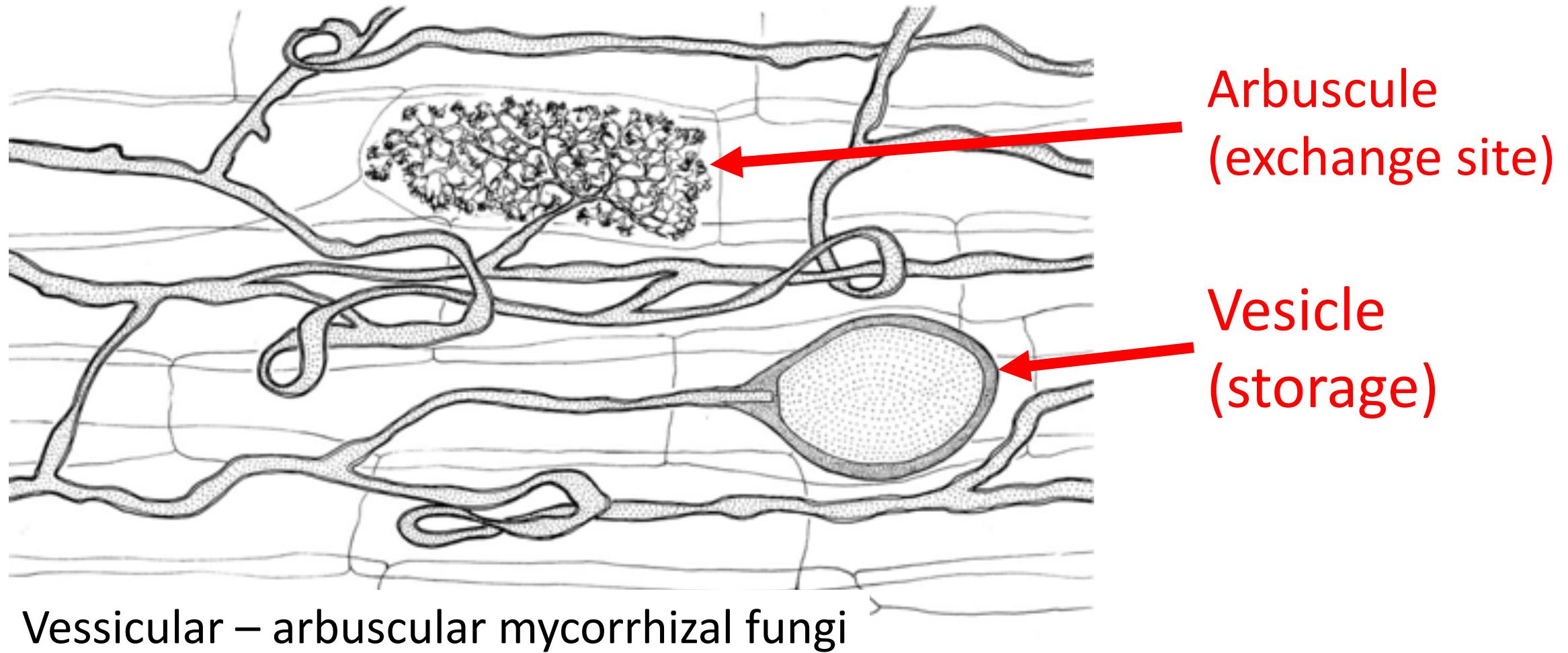


Vascular – arbuscular mycorrhizal fungi

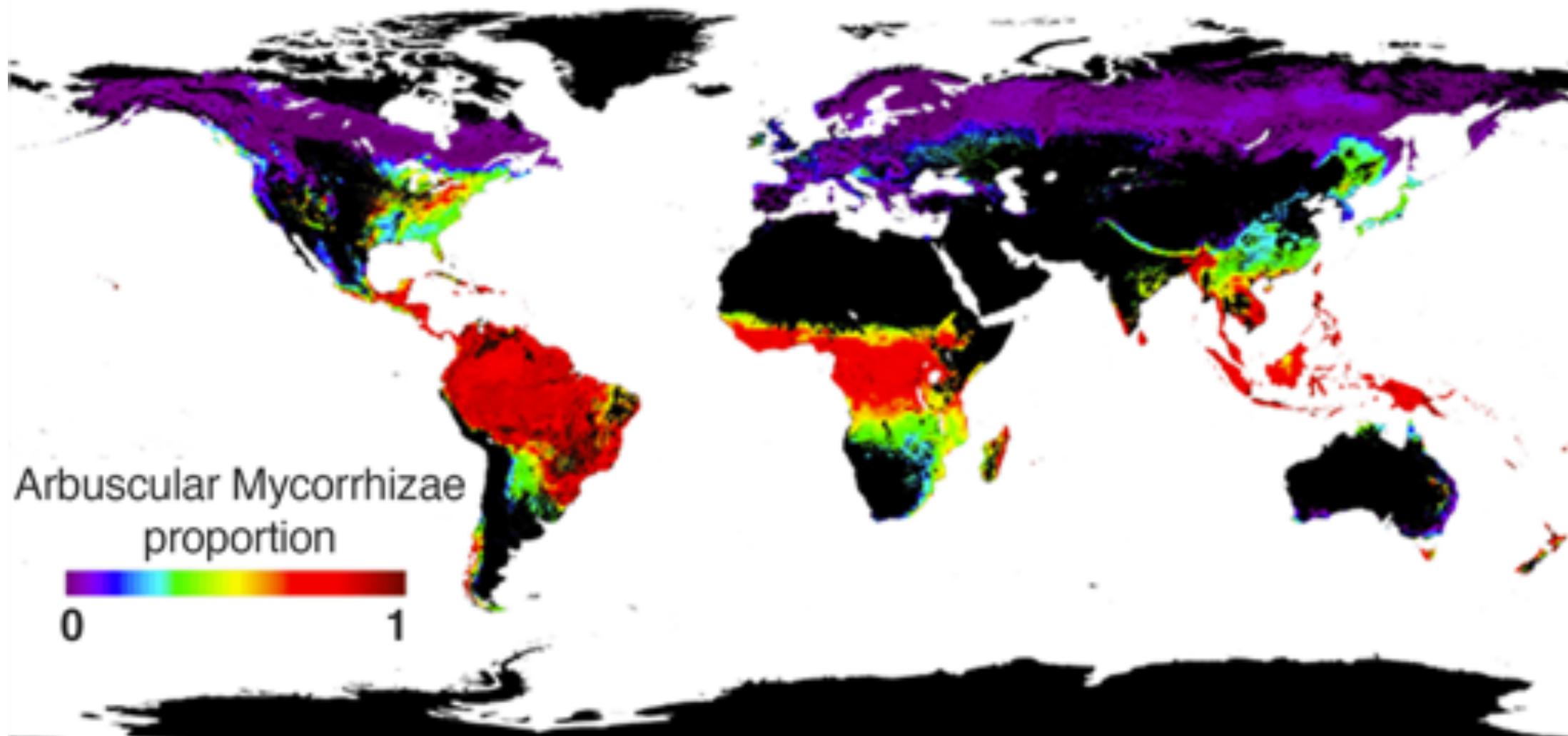
Exchange P
for C

Define the
plant-soil P
interface

Mycorrhizae are very important for plant P uptake

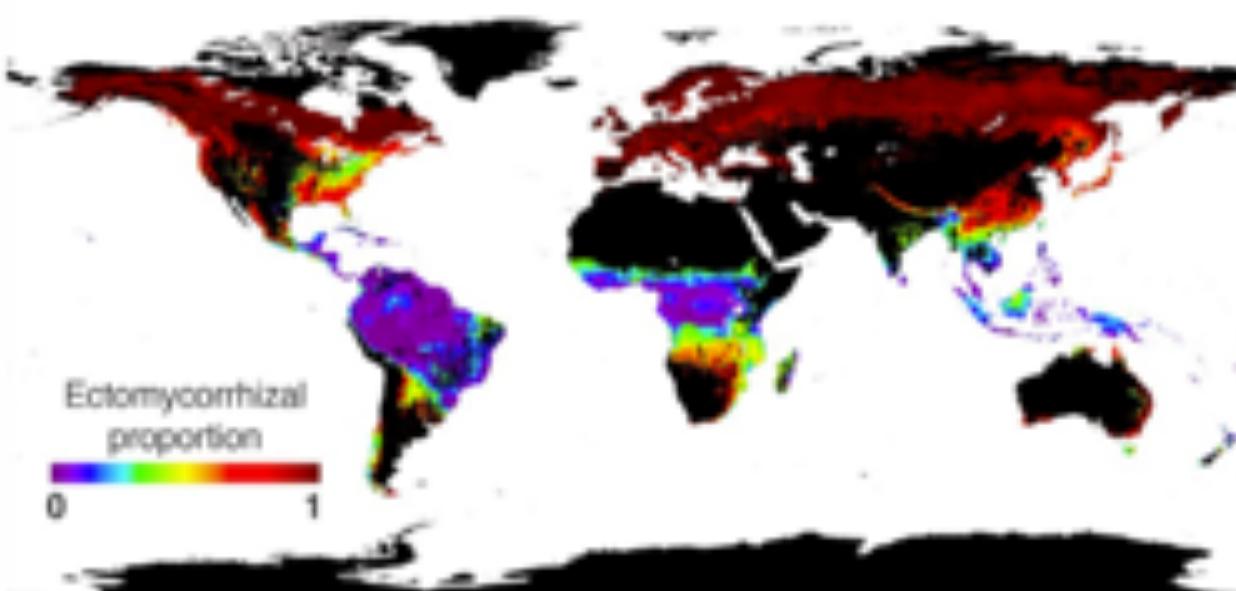


Arbuscular Mycorrhizae are mainly found in low-latitude regions with hot-and-wet climates

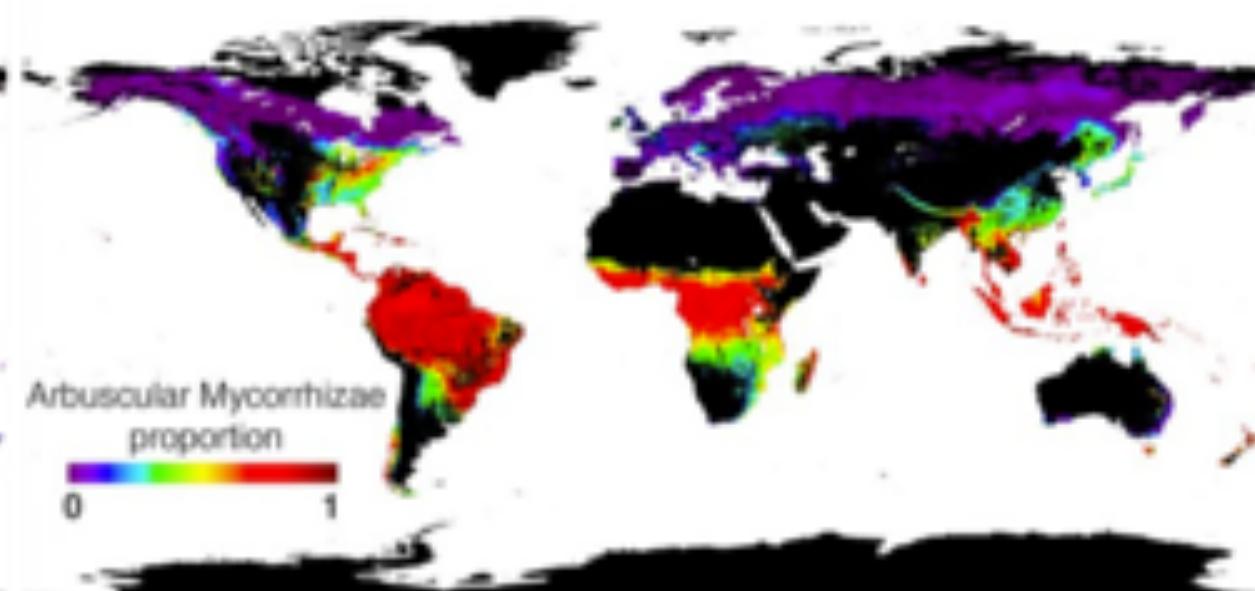


Ectomycorrhizal fungi are mainly found in high-latitude regions with a cold and dry climate

Arbuscular Mycorrhizae are mainly found in low-latitude regions with hot-and-wet climates



Source: Crowther Lab

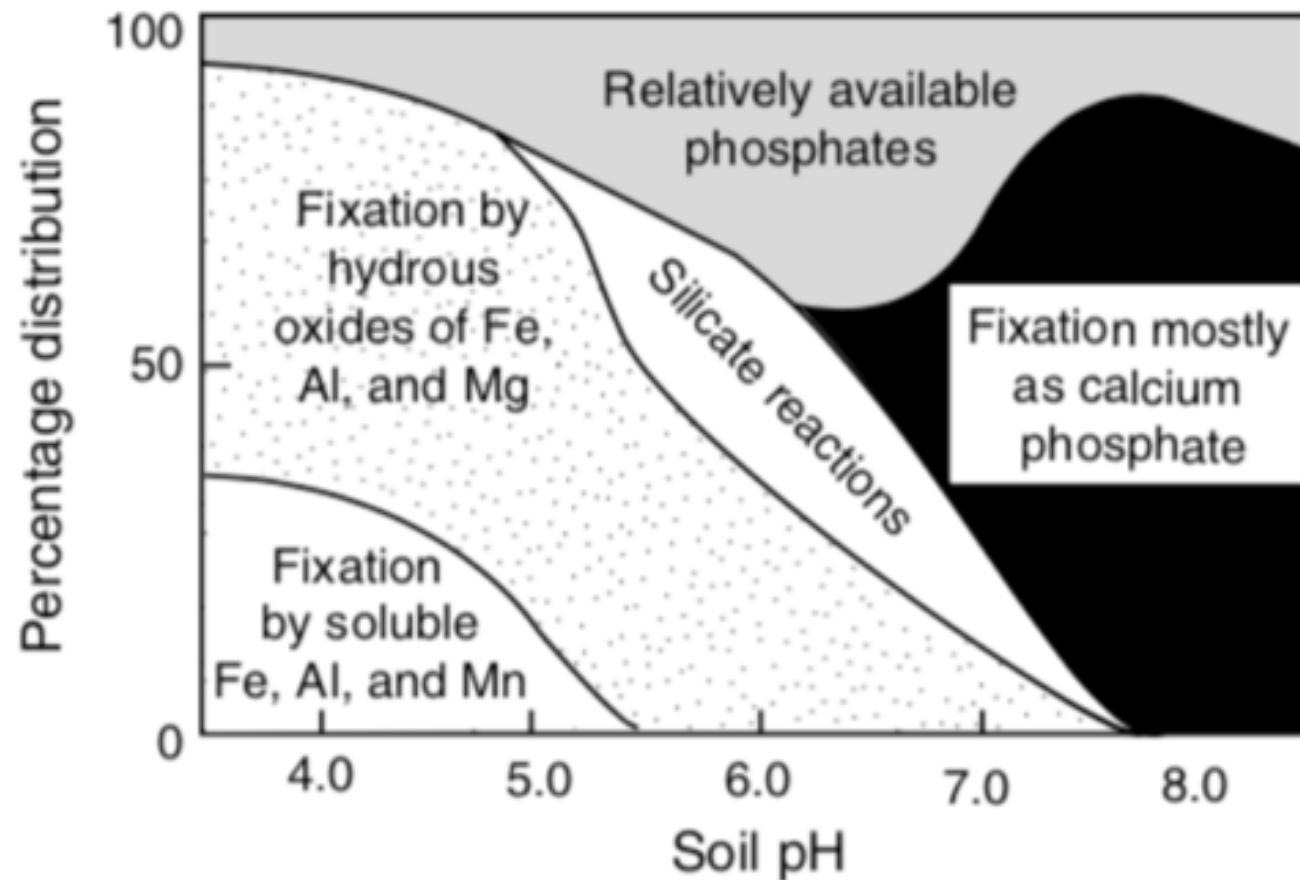


Source: Crowther Lab

Ectomycorrhizae get relatively more N than P

Arbuscular mycorrhizae get relatively more P than N

P binds to things, is more available at moderate pH



Agriculture

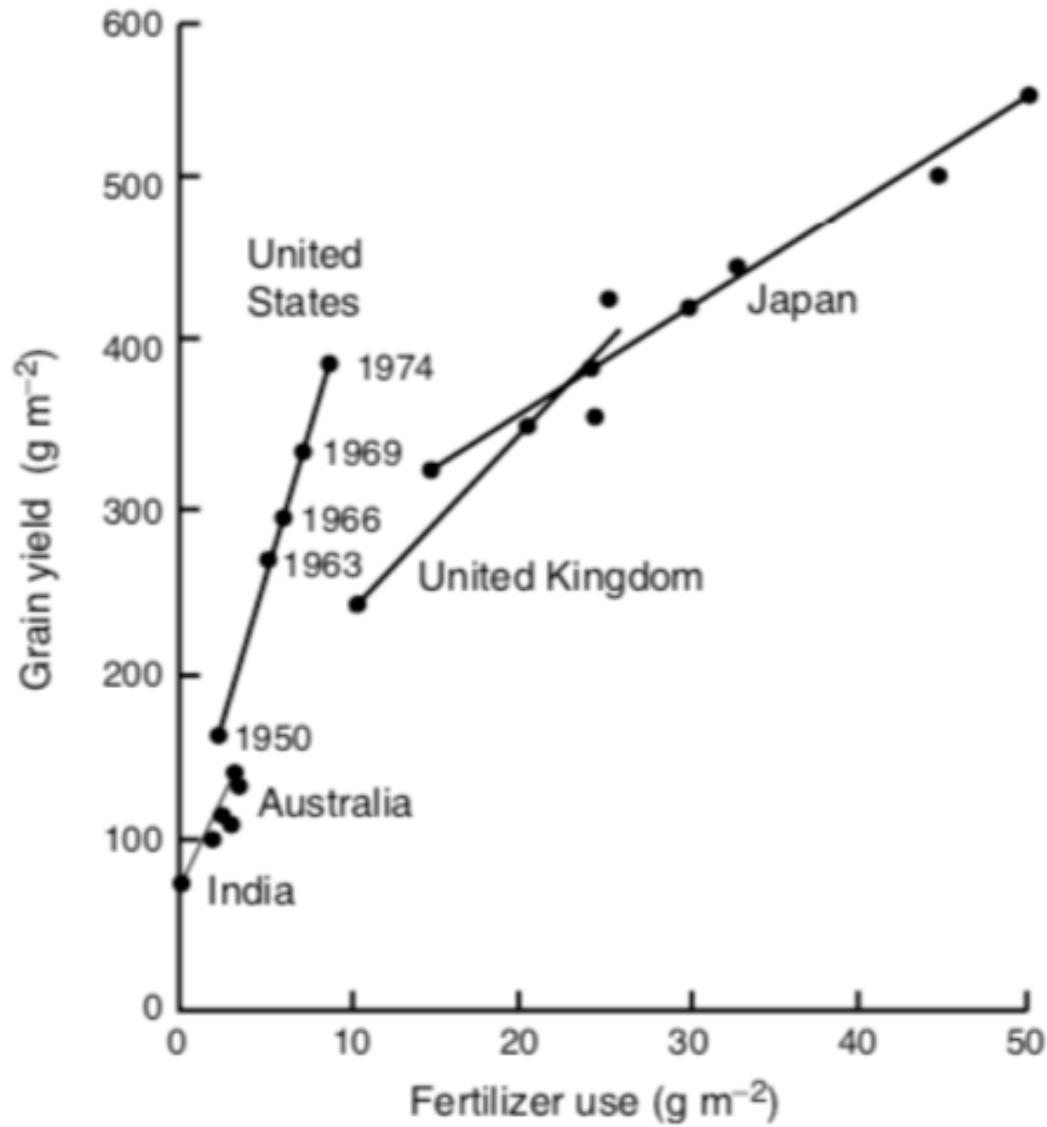
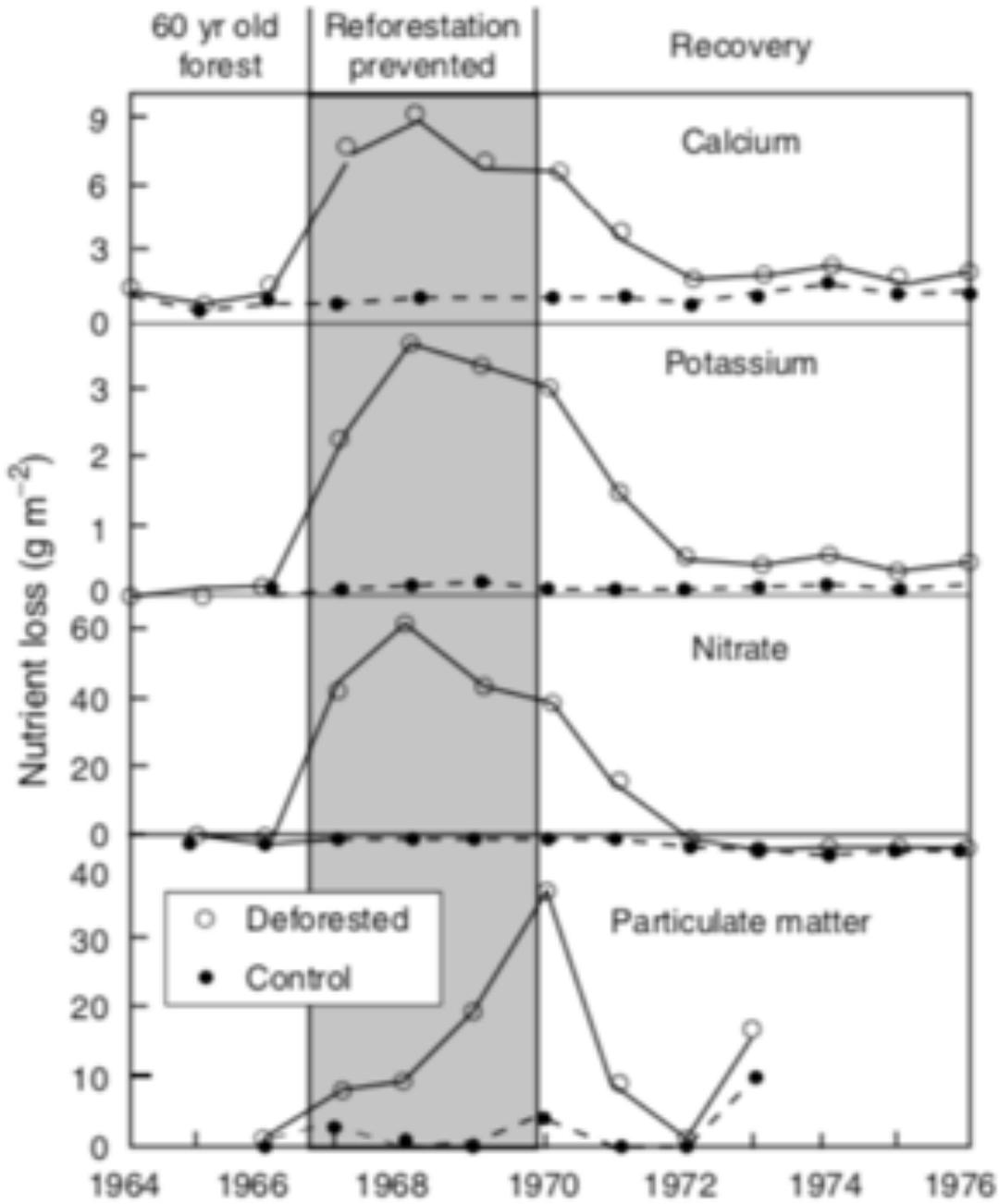


Fig. 9.14 Losses of calcium, potassium, nitrate, and particulate organic matter in stream water before and after deforestation of an experimental watershed at Hubbard Brook in the northeastern U.S. The shaded area shows the time interval during which vegetation was absent due to cutting of trees and herbicide application. Redrawn from Bormann and Likens (1979)



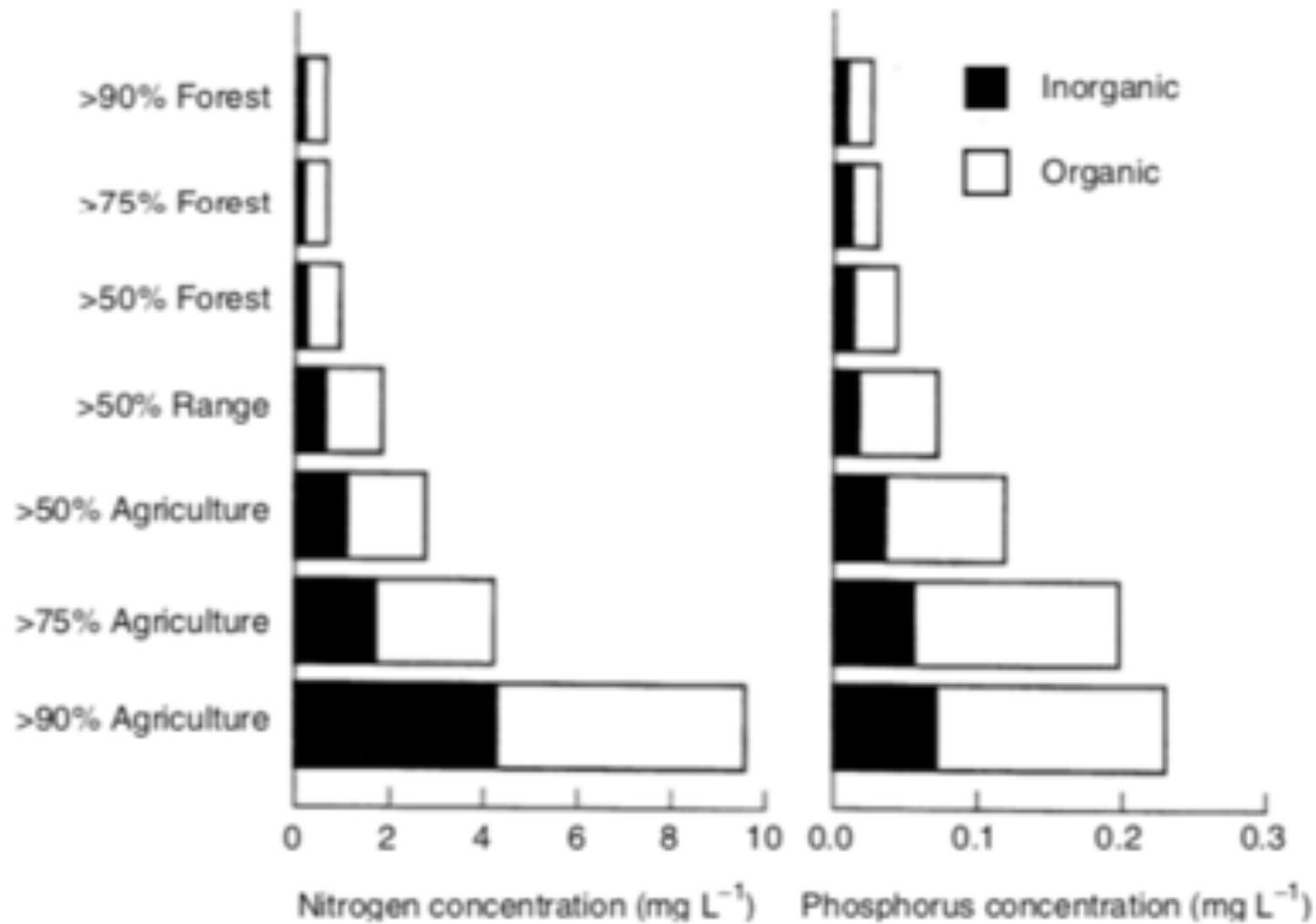
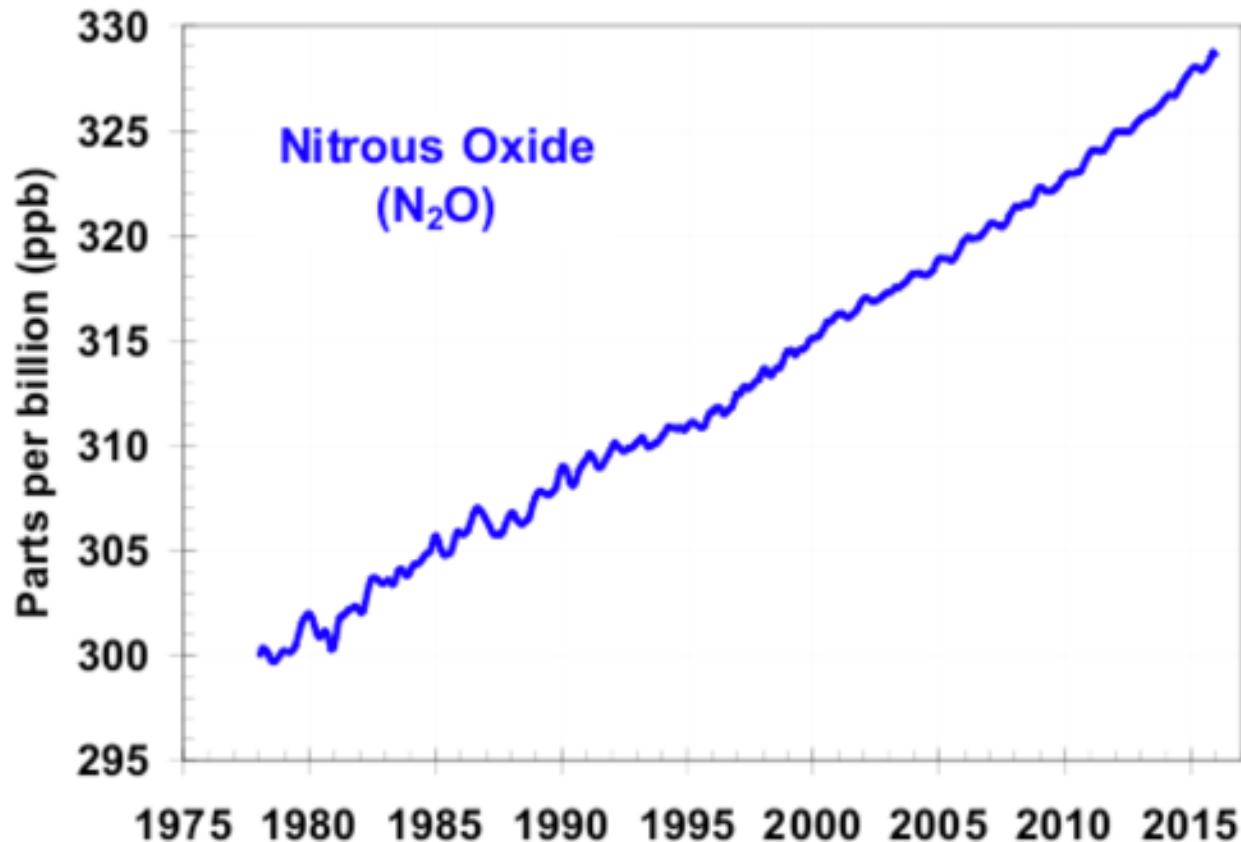
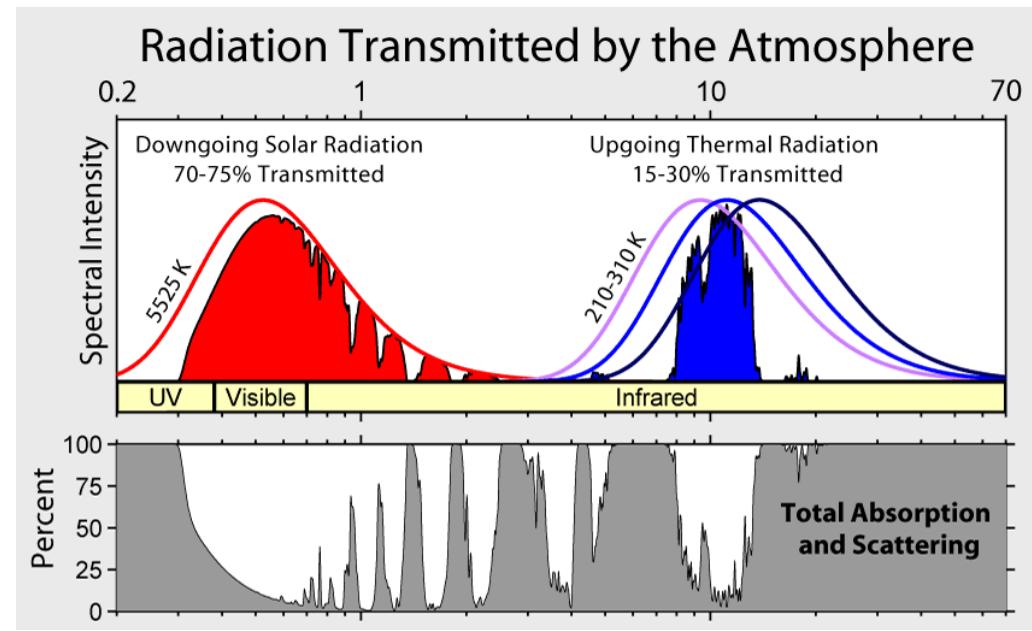
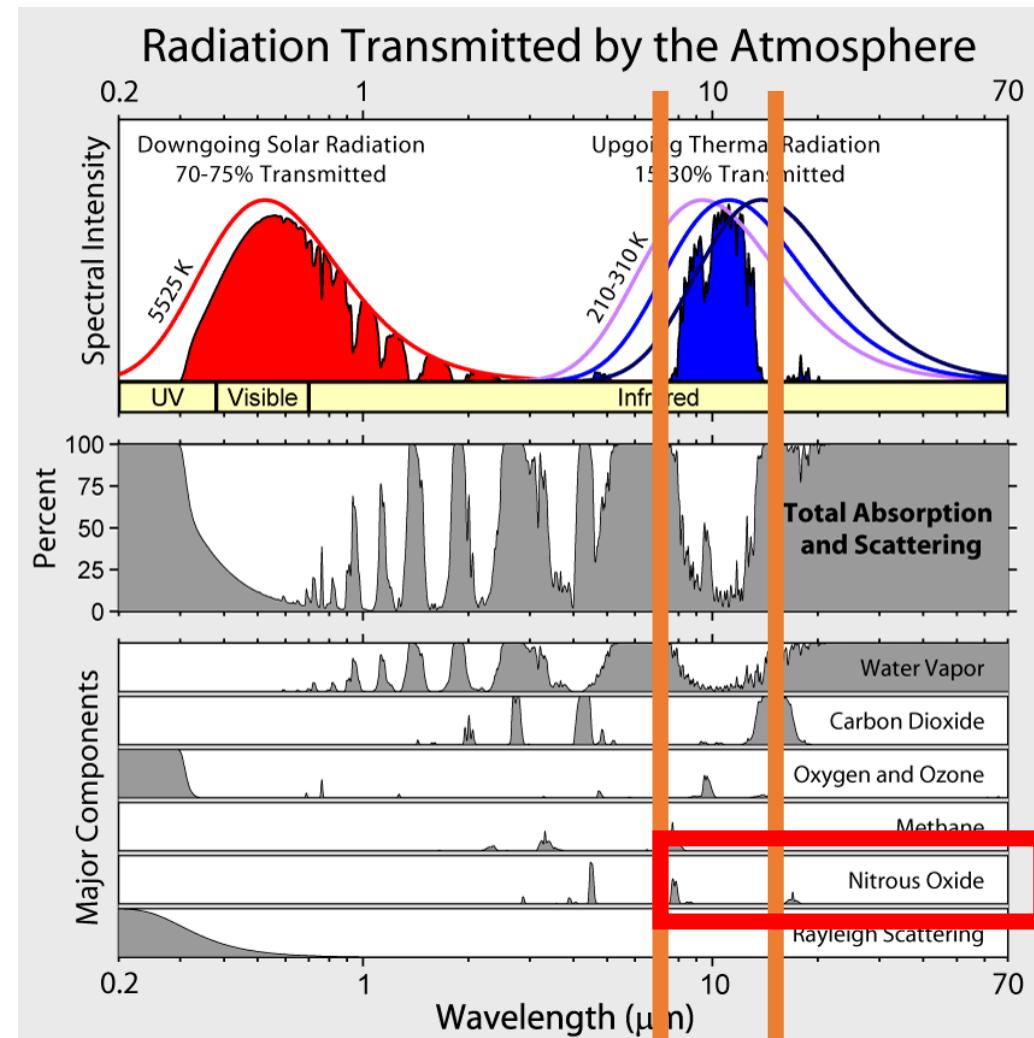


Fig. 9.4 Concentrations of organic and inorganic nitrogen and phosphorus in 928 relatively unpolluted U.S. streams in watersheds with varying degrees of conversion from forest to agriculture. Redrawn from Allan and Castillo (2007)



From agriculture and
fossil fuel burning





What might be the ecosystem impacts of fertilizer use?

How do we avoid these?

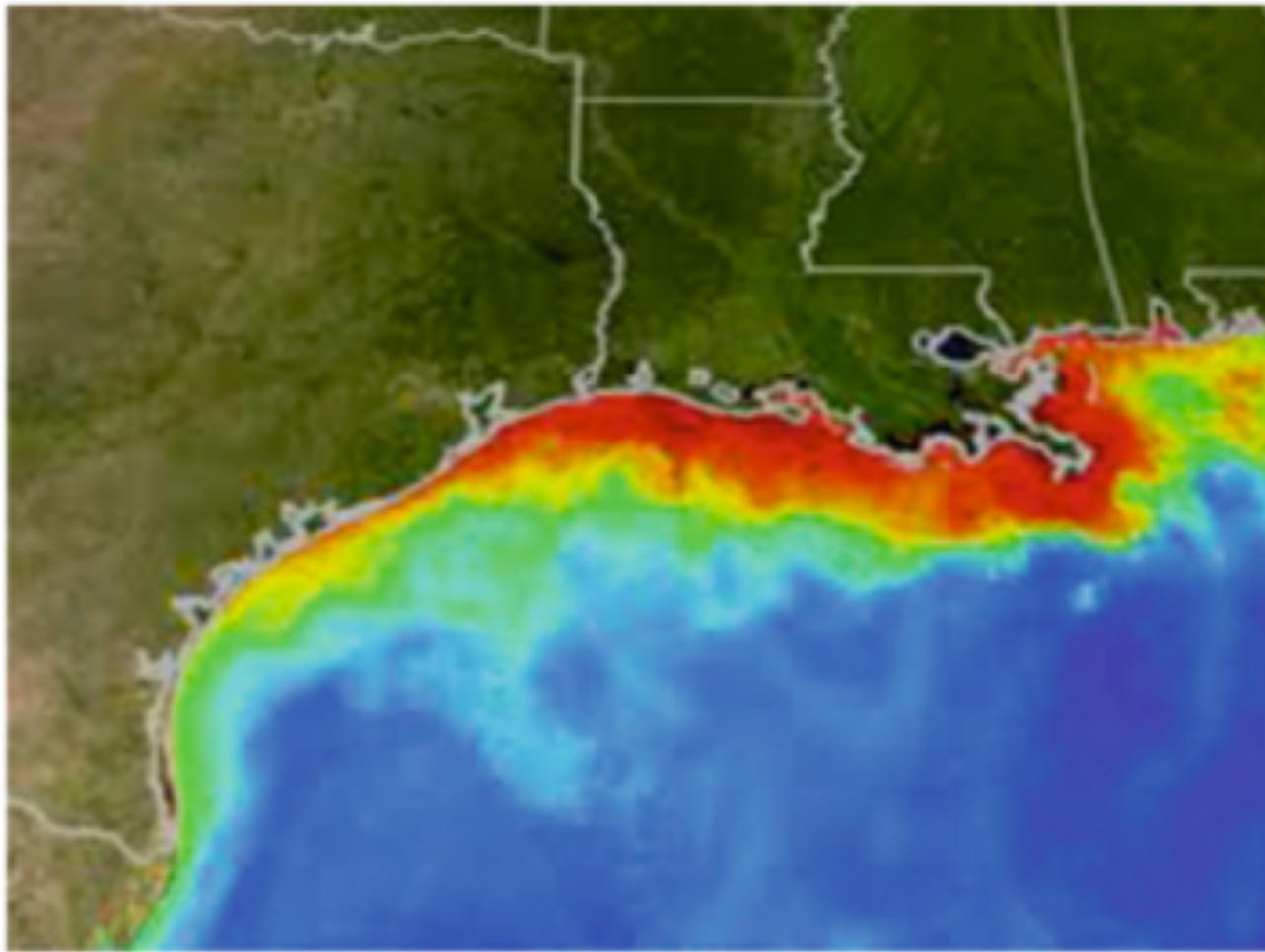


Fig. 9.1 Dead zone in the Gulf of Mexico, magnified by nutrient inputs from agricultural runoff from the Mississippi river drainage. Reds and oranges represent

high concentrations of phytoplankton and sediments (http://www.nasa.gov/vision/earth/environment/dead_zone.html)

