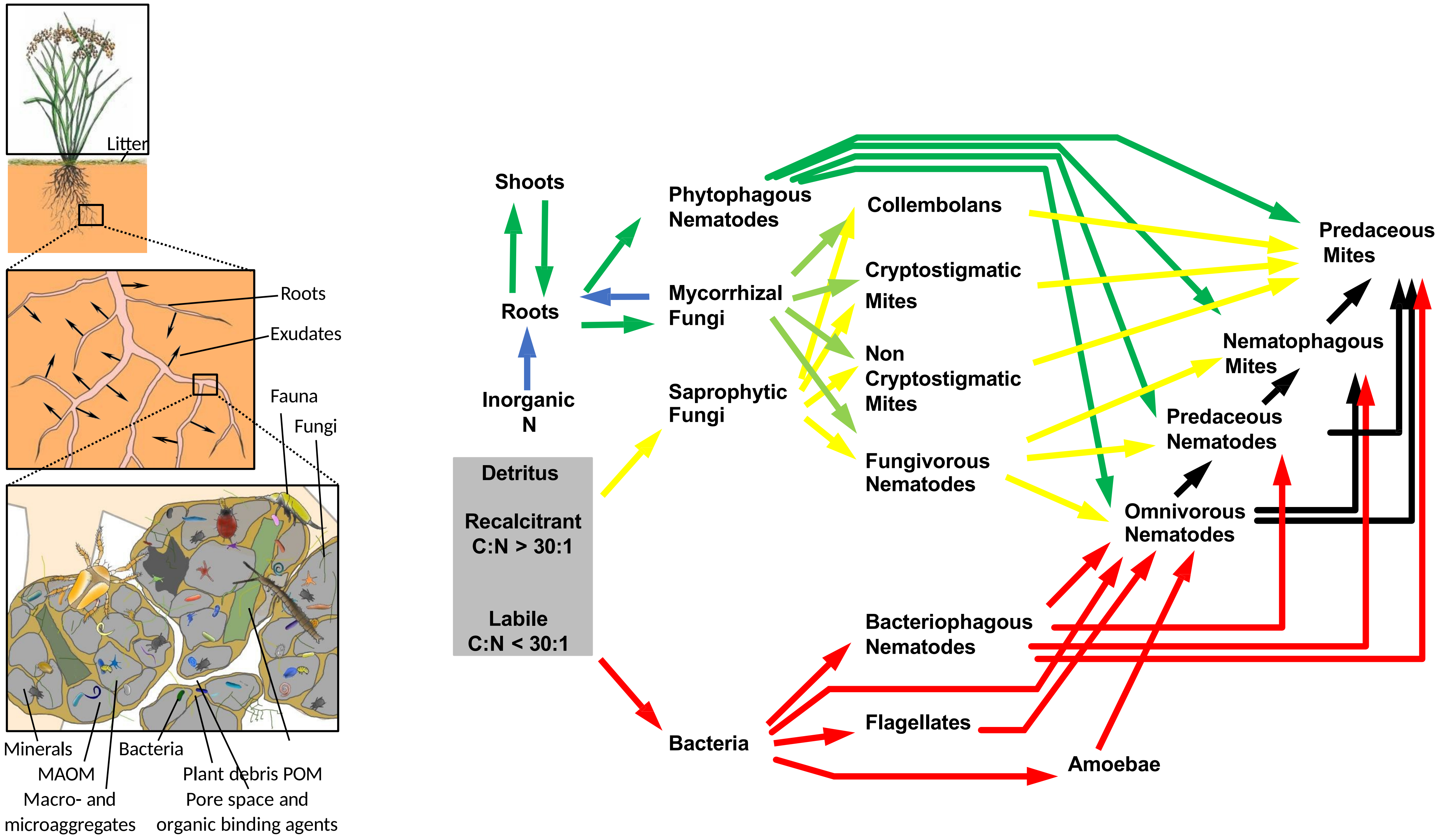
CHAPTER

6

The Biosphere
Biogeochemical Cycling on Land

OUTLINE



Litter
Roots
Exudates
Fauna
Fungi
Minerals
MAOM
Macro- and
microaggregates
Bacteria
Plant debris POM
Pore space and
organic binding agents
Shoots
Roots
Inorganic
N
Detritus
Recalcitrant
C:N > 30:1
Labile
C:N < 30:1
Phytophagous
Nematodes
Mycorrhizal
Fungi
Saprophytic
Fungi
Bacteria
Collembolans
Cryptostigmatic
Mites
Non
Cryptostigmatic
Mites
Fungivorous
Nematodes
Bacteriophagous
Nematodes
Flagellates
Amoebae
Predaceous
Mites
Nematophagous
Mites
Predaceous
Nematodes
Omnivorous
Nematodes

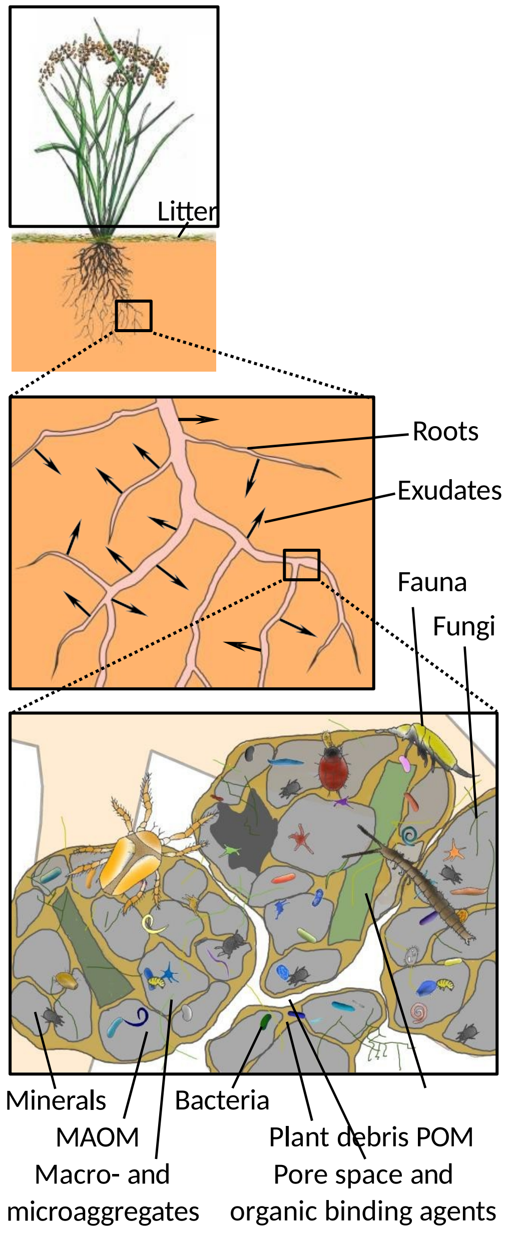
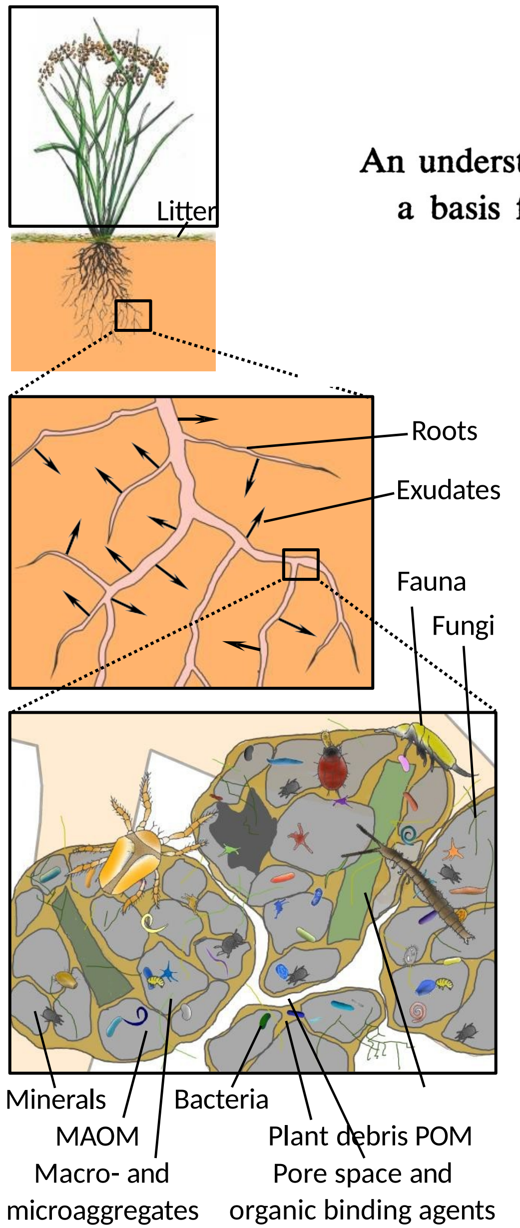


TABLE 6.1 Percentage of the Annual Requirement of Nutrients for Plant Growth in the Northern Hardwoods Forest at Hubbard Brook, New Hampshire, Which Could Be Supplied by Various Sources of Available Nutrients

Process	N	P	K	Ca	Mg
Growth requirement (Kg ha^{-1} yr^{-1})	115.4	12.3	66.9	62.2	9.5
Percentage of the requirement that could be supplied by:					
Intersystem inputs					
Atmospheric	18	0	1	4	6
Rock weathering	0	1	11	34	37
Intrasystem transfers					
Reabsorptions	31	28	4	0	2
Detritus turnover (includes return in throughfall and stemflow)	69	67	87	85	87

Note: Calculated using Eqs. 6.2 and 6.3.
Source: Reabsorption data are from Ryan and Bormann (1982). Data for N, K, Ca, and Mg are from Likens and Bormann (1995) and for P from Yanai (1992).



The Strategy of Ecosystem Development

An understanding of ecological succession provides a basis for resolving man's conflict with nature.

Eugene P. Odum

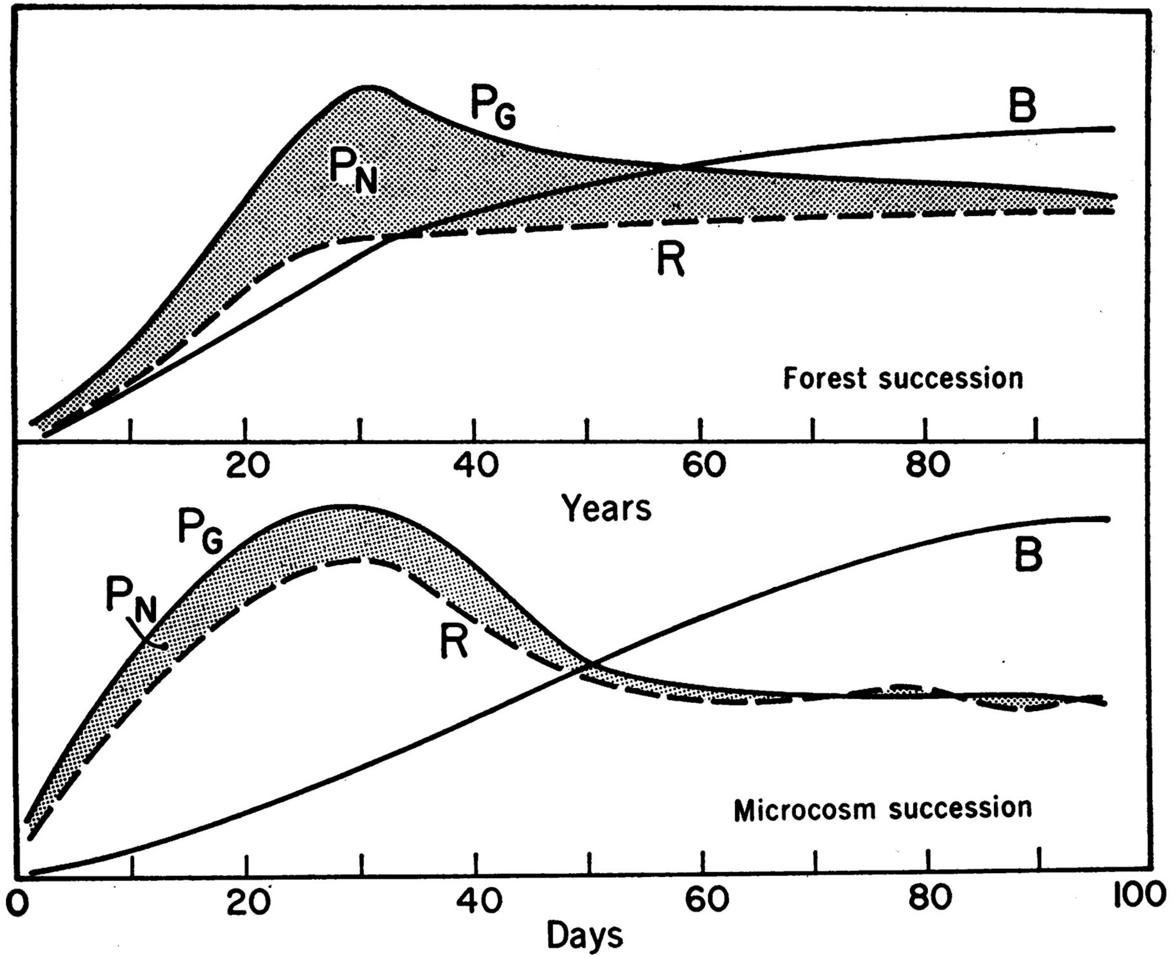
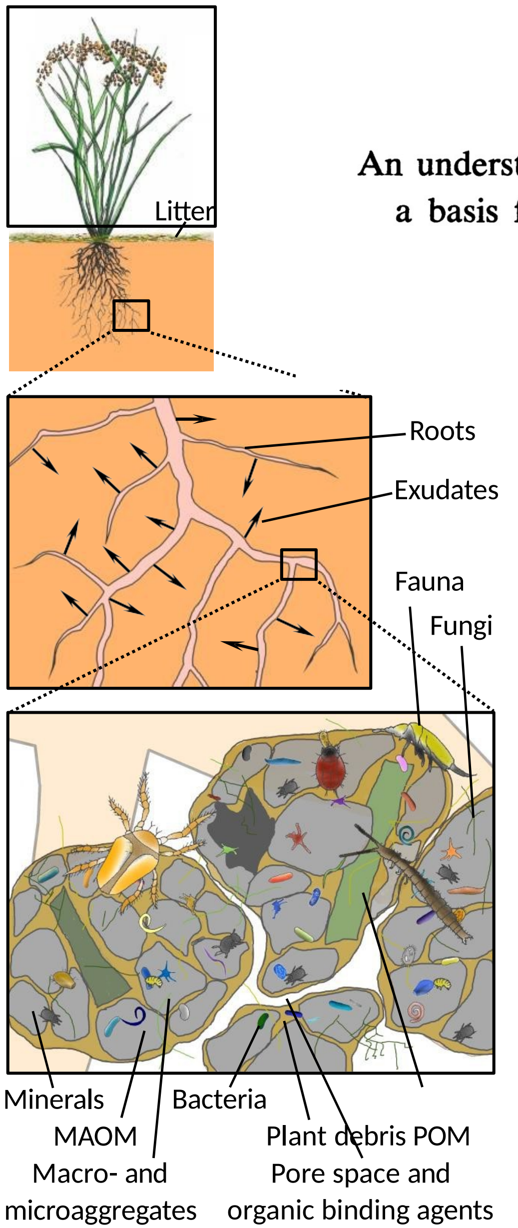


Fig. 1. Comparison of the energetics of succession in a forest and a laboratory microcosm. P_G, gross production; P_N, net production; R, total community respiration; B, total biomass.



The Strategy of Ecosystem Development

An understanding of ecological succession provides a basis for resolving man's conflict with nature.

Eugene P. Odum

Table 1. A tabular model of ecological succession: trends to be expected in the development of ecosystems.

Ecosystem attributes	Developmental stages	Mature stages
Community energetics		
1. Gross production/community respiration (*P/R* ratio)	Greater or less than 1	Approaches 1
2. Gross production/standing crop biomass (*P/B* ratio)	High	Low
3. Biomass supported/unit energy flow (*B/E* ratio)	Low	High
4. Net community production (yield)	High	Low
5. Food chains	Linear, predominantly grazing	Weblike, predominantly detritus
Community structure		
6. Total organic matter	Small	Large
7. Inorganic nutrients	Extrabiotic	Intrabiotic
8. Species diversity—variety component	Low	High
9. Species diversity—equitability component	Low	High
10. Biochemical diversity	Low	High
11. Stratification and spatial heterogeneity (pattern diversity)	Poorly organized	Well-organized
Life history		
12. Niche specialization	Broad	Narrow
13. Size of organism	Small	Large
14. Life cycles	Short, simple	Long, complex
Nutrient cycling		
15. Mineral cycles	Open	Closed
16. Nutrient exchange rate, between organisms and environment	Rapid	Slow
17. Role of detritus in nutrient regeneration	Unimportant	Important
Selection pressure		
18. Growth form	For rapid growth ("*r*-selection")	For feedback control ("*K*-selection")
19. Production	Quantity	Quality
Overall homeostasis		
20. Internal symbiosis	Undeveloped	Developed
21. Nutrient conservation	Poor	Good
22. Stability (resistance to external perturbations)	Poor	Good
23. Entropy	High	Low
24. Information	Low	High

Reflection 7

I thought it was interesting learning about the different necessities required for decomposition and plant growth. Different nutrients reflect different properties of the plants, such as magnesium in chlorophyll. The assignment this week got me thinking about graduate school, even though I'm not planning on going immediately after I graduate. It was interesting to think about what I would study if I did want to go to graduate school at some point.

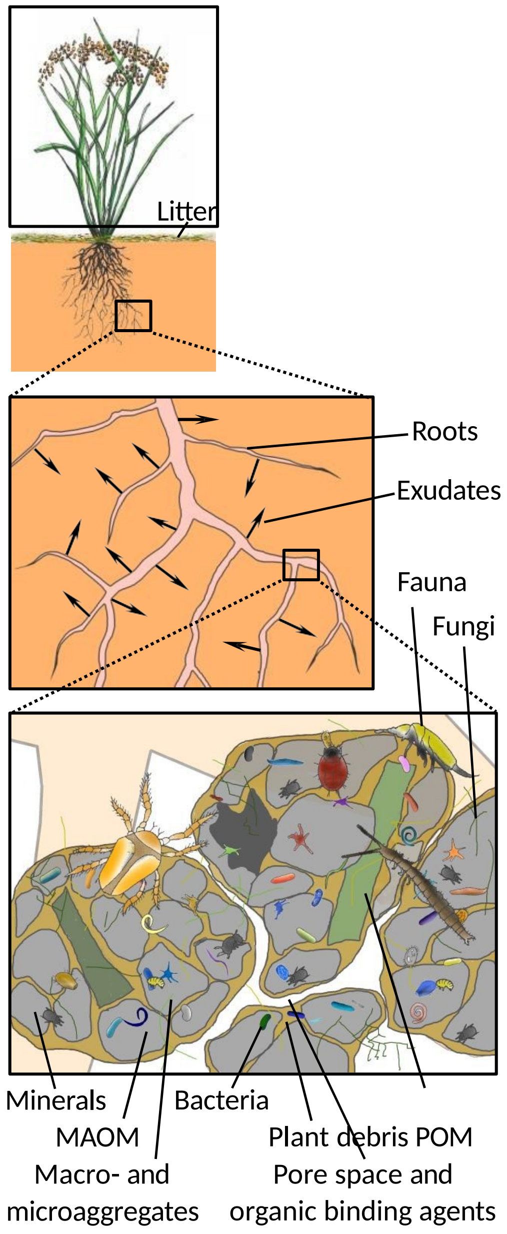
Despite initial concerns about assignment two, I feel it went well and I'm very happy with my result. Though mostly beyond the scope of this class, it helped me outline a research/business interest of mine that I've been pursuing for a while. The literature review was interesting and helped me realize that the technology required for the idea is closer than I previously thought. This revelation has given me a lot to think about and has me reconsidering my 5-10 year plan.

One thing that I found interesting this week was discussing Odum's research on ecological succession and how that can provide a resolution to the human/nature conflict. The trends between development and mature ecosystem stages, and how human disturbances keep these systems in the development stage. Initially, my mind went to when I learned about seral stages of succession in rangelands in NR220. I was also excited to finish assignment 2 because I am starting to get a good idea of the research that I want to look into in the future.

Oxidized $\longrightarrow$ Reduced

Oxidized ↑ Reduced	H_2O/O_2	C	N	S
H_2O/O_2	X	Photosynthesis $CO_2 \longrightarrow C$ $H_2O \longrightarrow O_2$		
C	Respiration $C \longrightarrow CO_2$ $O_2 \longrightarrow H_2O$	X	Denitrification $C \longrightarrow CO_2$ $NO_3 \longrightarrow N_2$	Sulfate-Reduction $C \longrightarrow CO_2$ $SO_4 \longrightarrow H_2S$
N	Heterotrophic Nitrification $NH_4 \longrightarrow NO_3$ $O_2 \longrightarrow H_2O$	Chemoautotrophy (Nitrification) $NH_4 \longrightarrow NO_3$ $CO_2 \longrightarrow C$	Anammox $NH_4 + NO_2 \rightarrow N_2 + 2H_2O$	?
S	Sulfur Oxidation $S \longrightarrow SO_4$ $O_2 \longrightarrow H_2O$	Chemoautotrophy (Sulfur-based Photosynthesis) $S \longrightarrow SO_4$ $CO_2 \longrightarrow C$	Autotrophic Denitrification $S \longrightarrow SO_4$ $NO_3 \longrightarrow N_2/NH_4$	X

FIGURE 1.4 A matrix showing how cellular metabolisms couple oxidation and reduction reactions. The cells in the matrix are occupied by organisms or a consortium of organisms that reduce the element at the top of the column, while oxidizing an element at the beginning of the row. *Source: From Schlesinger et al. (2011).*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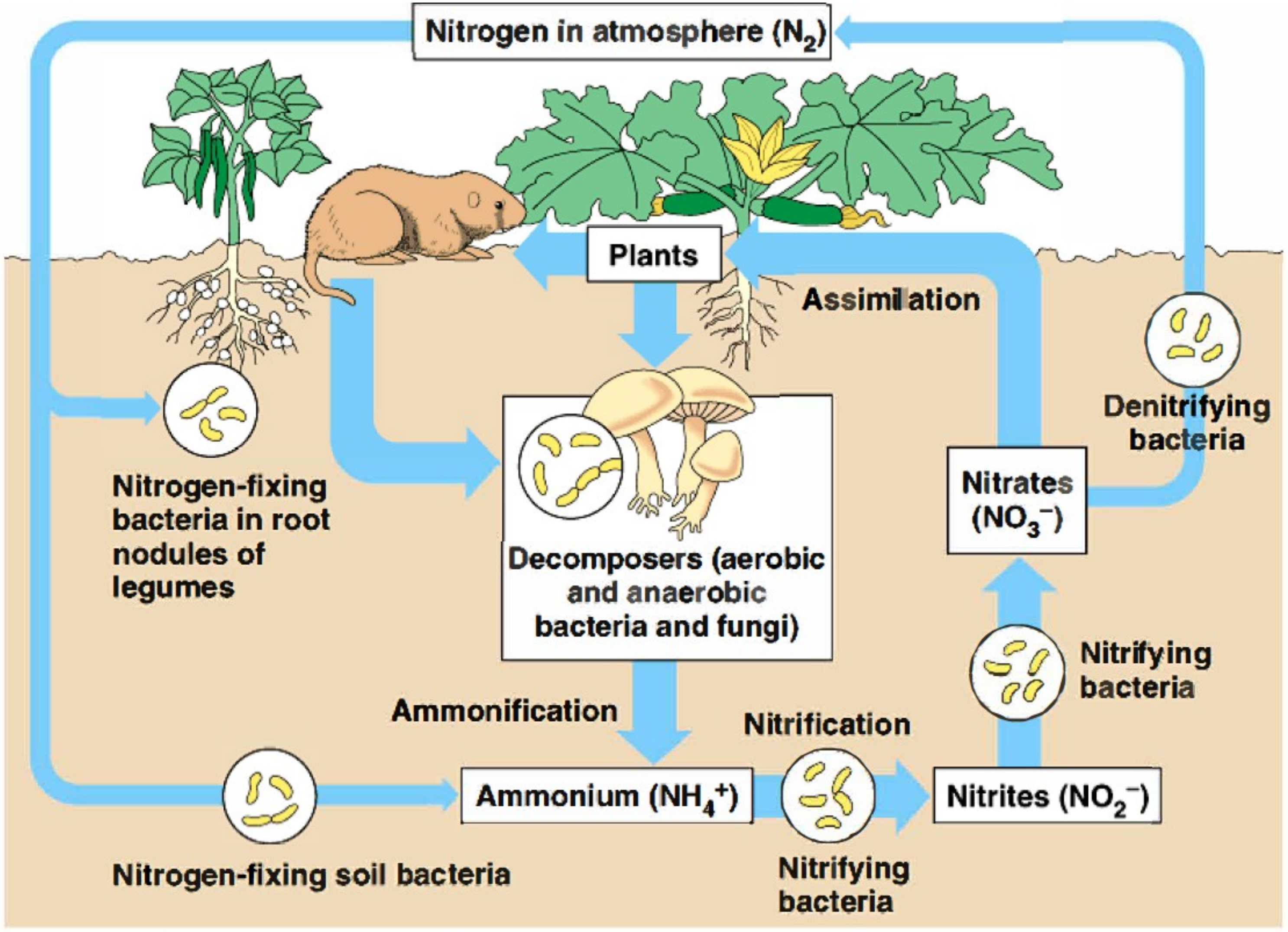
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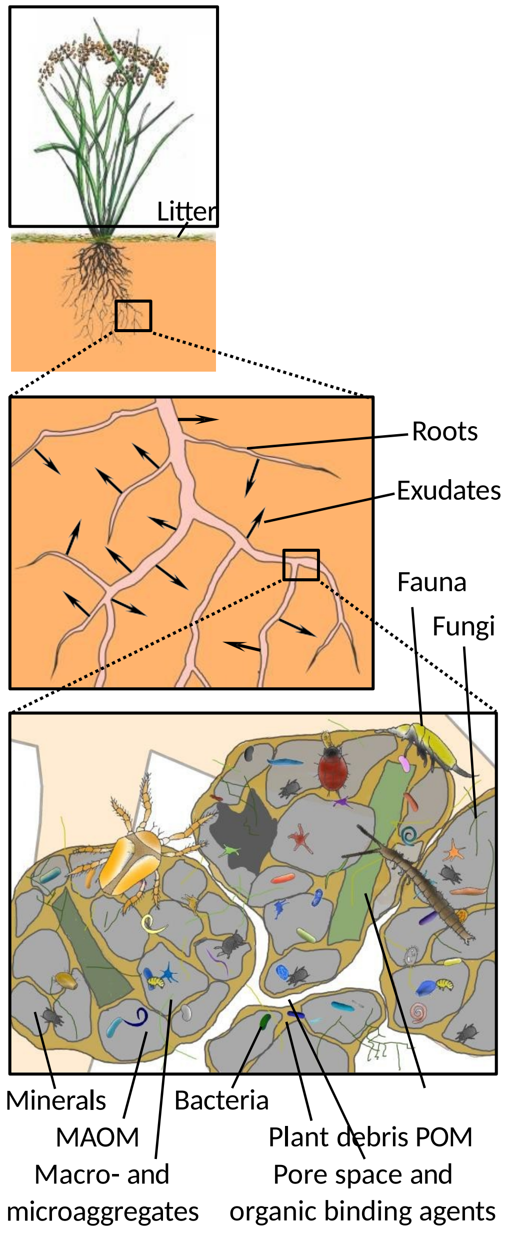

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nature geoscience
PUBLISHED ONLINE: 25 APRIL 2010 | DOI:10.1038/NGEO846

Soil-carbon response to warming dependent on microbial physiology

Steven D. Allison[1]*, Matthew D. Wallenstein[2] and Mark A. Bradford[3]

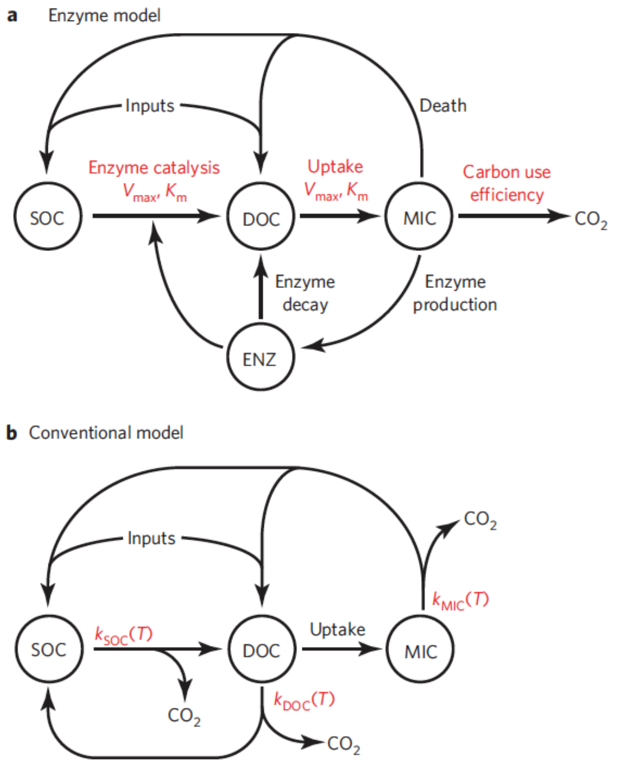
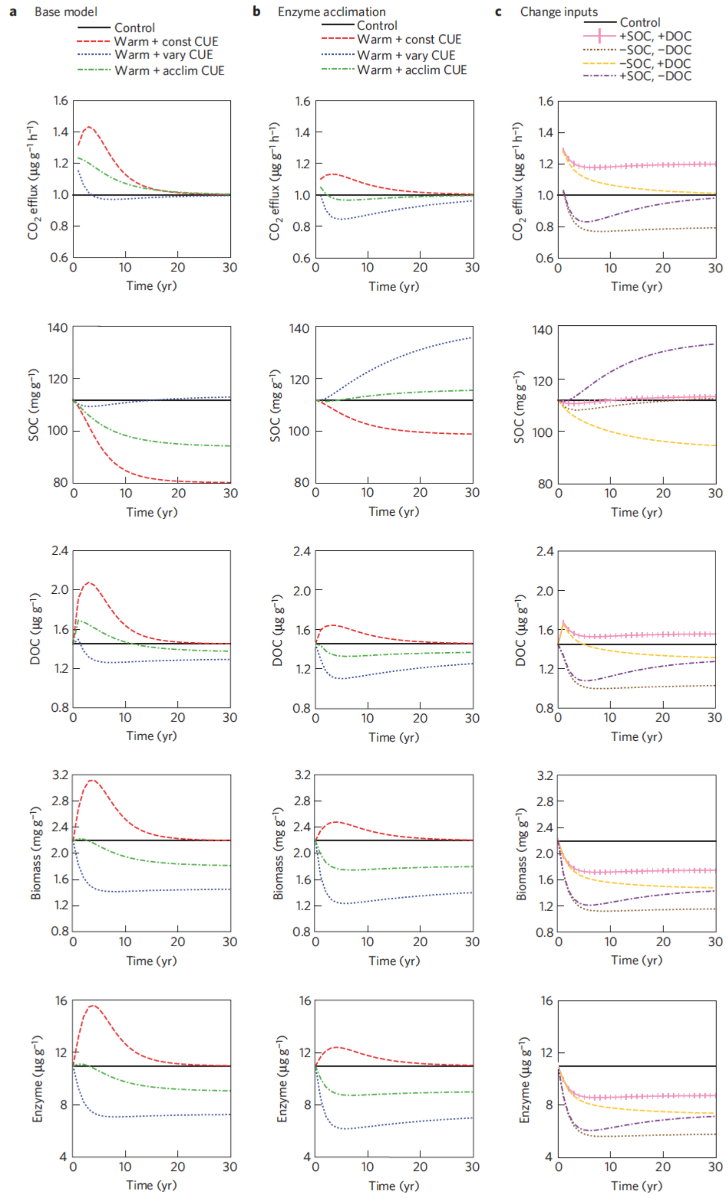


Figure 1 | Diagram of soil C models. Structure of the microbial-enzyme (**a**) and conventional (**b**) models of soil C decomposition under warming. Temperature-sensitive parameters are shown in red. The distinguishing feature of the enzyme model is that microbial biomass (MIC) affects the conversion of SOC to DOC through the production of extracellular enzymes (ENZ). In the conventional model, microbial processes are not explicitly coupled to soil C turnover, so changes in microbial biomass and enzyme production cannot feed back on decomposition.



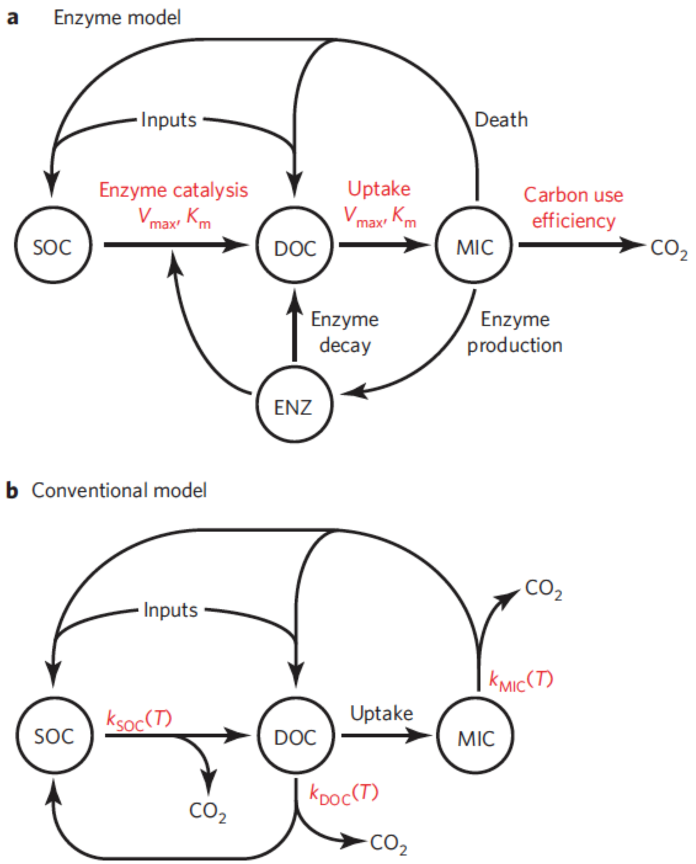


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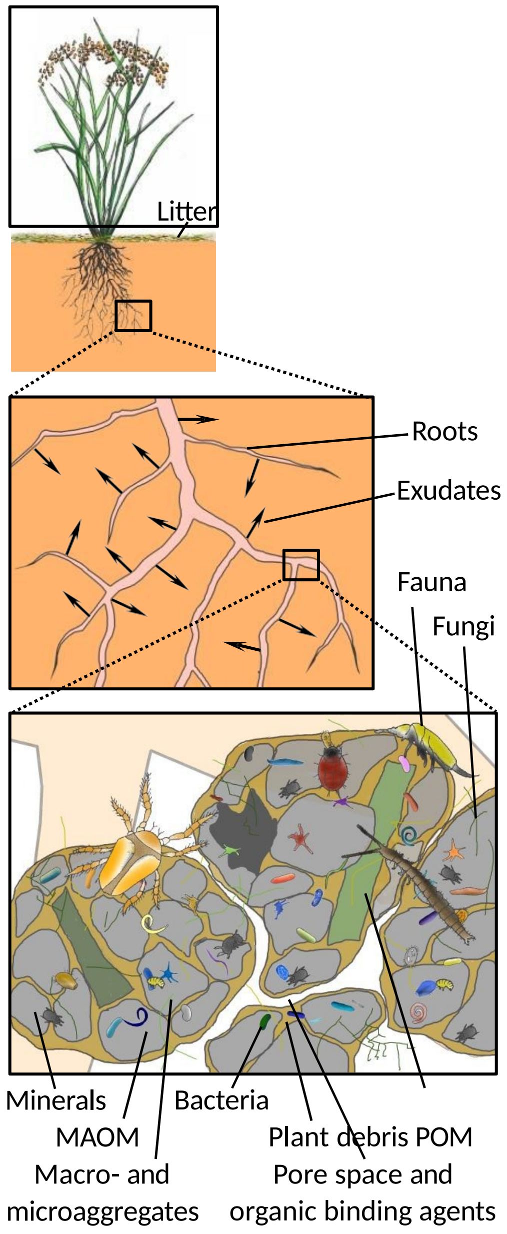
Table 1 | Modelled changes in SOC pool size.

Scenario*	30 yr change in SOC pool size (%)
Control	0
CUE varies	+1
CUE acclimates	−16
CUE acclimates + enzyme acclimation	+3
Low SOC, high DOC inputs + CUE varies	−15
LH inputs + CUE varies + enzyme acclimation	+2
LH inputs + CUE acclimates	−29
LH inputs + CUE acclimates + enzyme acclimation	−13

*Control run and model scenarios predicting an ephemeral rise in soil respiration and reduced microbial biomass in response to 5 °C warming, consistent with empirical observations[3-5,14]. LH inputs = Low SOC, high DOC inputs.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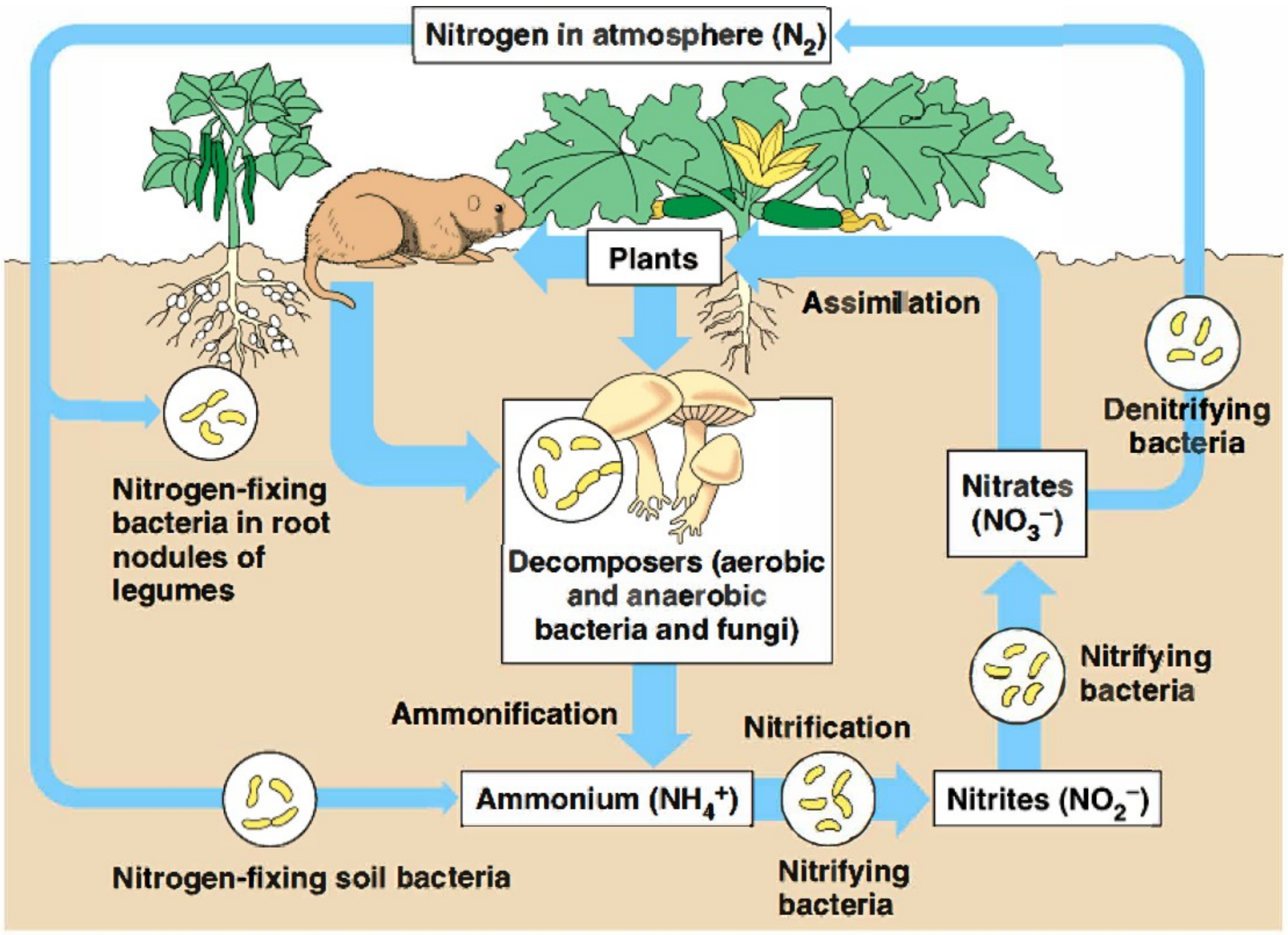
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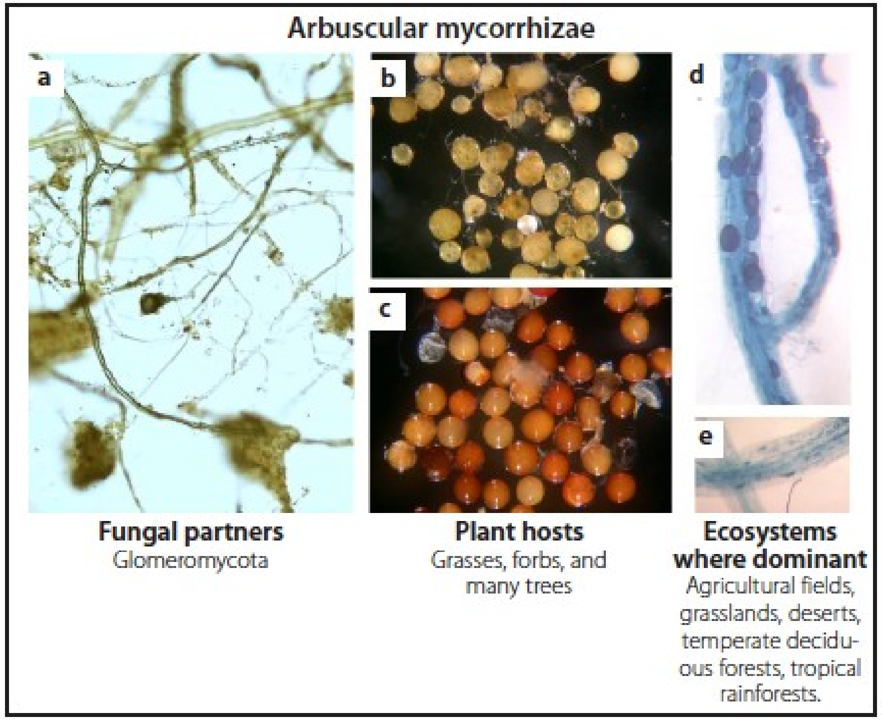
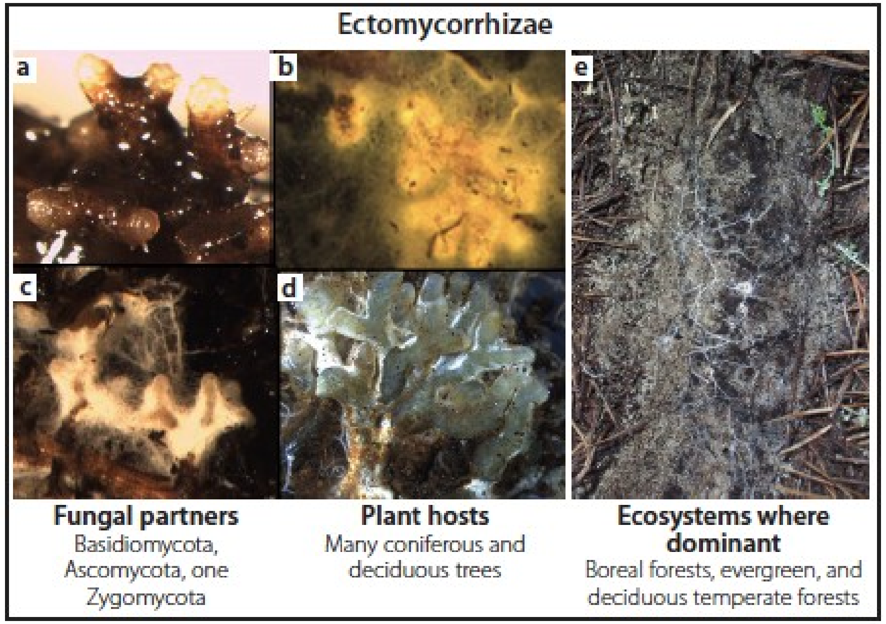
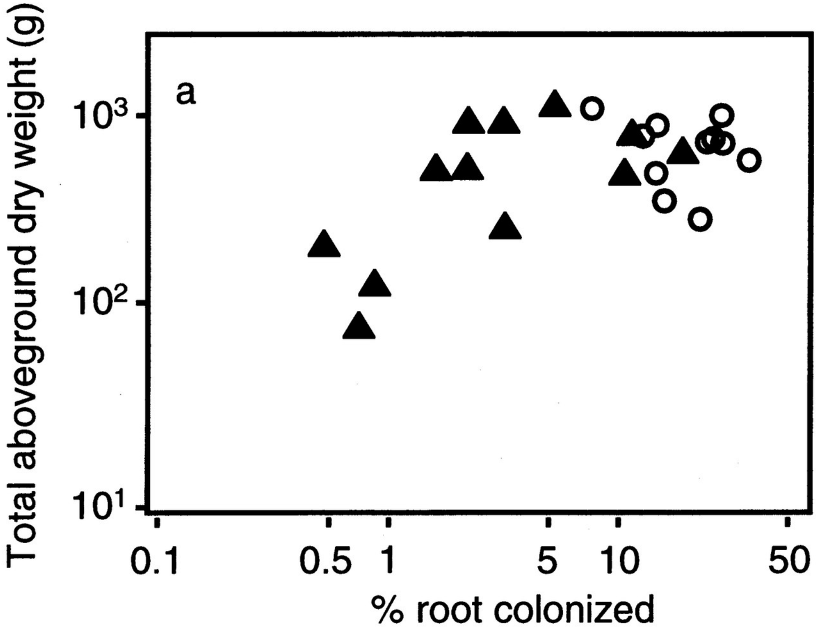






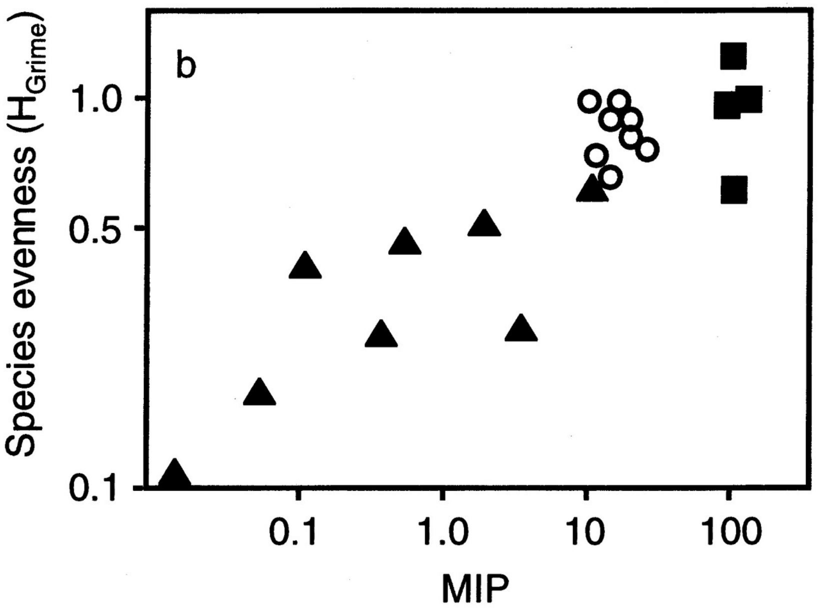
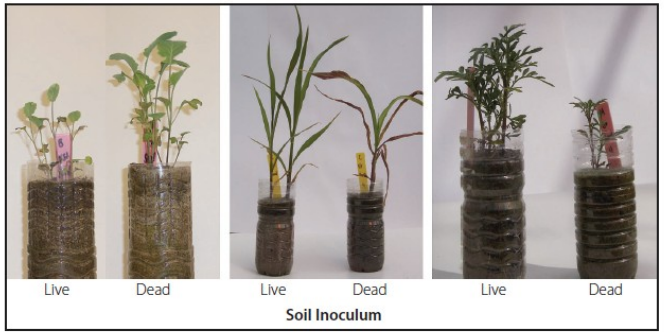


Figure 3. Results of the experiment can be illustrated with photographs. These pictures show that after eight weeks in a warm greenhouse, broccoli (left) grew better without mycorrhizal fungi and other organisms in the living soil, while corn and marigolds (middle and right) grew better with these soil organisms.



Biological Invasion by Myrica faya Alters Ecosystem Development in Hawaii

Peter M. Vitousek; Lawrence R. Walker; Louis D. Whiteaker; Dieter Mueller-Dombois; Pamela A. Matson

Science, New Series, Vol. 238, No. 4828 (Nov. 6, 1987), 802-804.

Table 1. Diameter increment (in millimeters per year, with standard errors in parentheses) of control and fertilized individuals of the native tree *Metrosideros polymorpha* in young, intermediate-aged, and old sites. Fertilizer treatments, application rates, and statistical design are in (*11*). No *Myrica faya* was present on any plot.

Site	Control	Nitrogen-fertilized	Significance level	Effect of other nutrients
1959 ash	6.6 (0.8)	11.6 (0.9)	$P < 0.001$	NS*
1790 ash	0.4 (0.1)	0.8 (0.1)	$P < 0.01$	NS*
Old ash	4.4 (0.7)	5.5 (0.9)	NS*	
Open canopied†	0.6 (0.1)	2.4 (0.3)	$P < 0.001$	

*NS, not significant ($P > 0.05$). †Many canopy trees and all of the understory were eliminated by volcanic cinder from a 1959 eruption; measurements were made on the surviving canopy trees.

Table 2. Sources of nitrogen (in kilograms per hectare per year) in open-canopied sites with and without populations of the exotic nitrogen-fixer *Myrica faya*.

Source	No *Myrica*	With *Myrica*
Rainfall (*16*)	5	5
Native nitrogen fixation (*17*) by		
Leaf litter	0.2	0.3
Decaying wood	0.1	<0.1
Lichens	0.2	0.2
Bryophyte mats	<0.1	<0.1
Nitrogen fixation by *Myrica faya* (*14*)	0	18
Total	5.5	23.5

Oxidized $\longrightarrow$ Reduced

Reduced $\longrightarrow$ Oxidized

	H_2O/O_2	C	N	S
H_2O/O_2	X	Photosynthesis $CO_2 \longrightarrow C$ $H_2O \longrightarrow O_2$		
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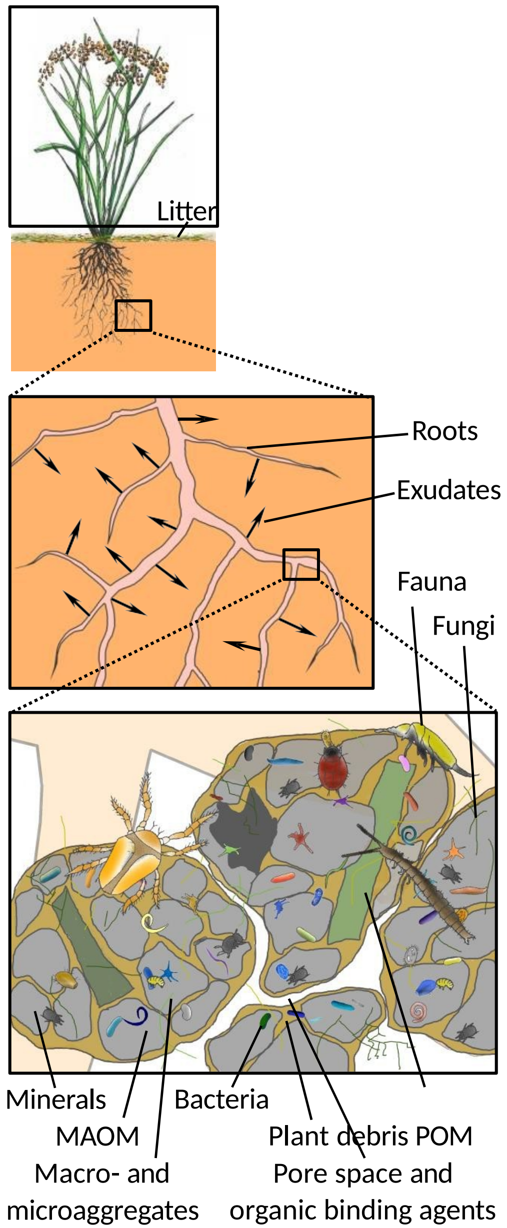
FIGURE 1.4 A matrix showing how cellular metabolisms couple oxidation and reduction reactions. The cells in the matrix are occupied by organisms or a consortium of organisms that reduce the element at the top of the column, while oxidizing an element at the beginning of the row. *Source: From Schlesinger et al. (2011).*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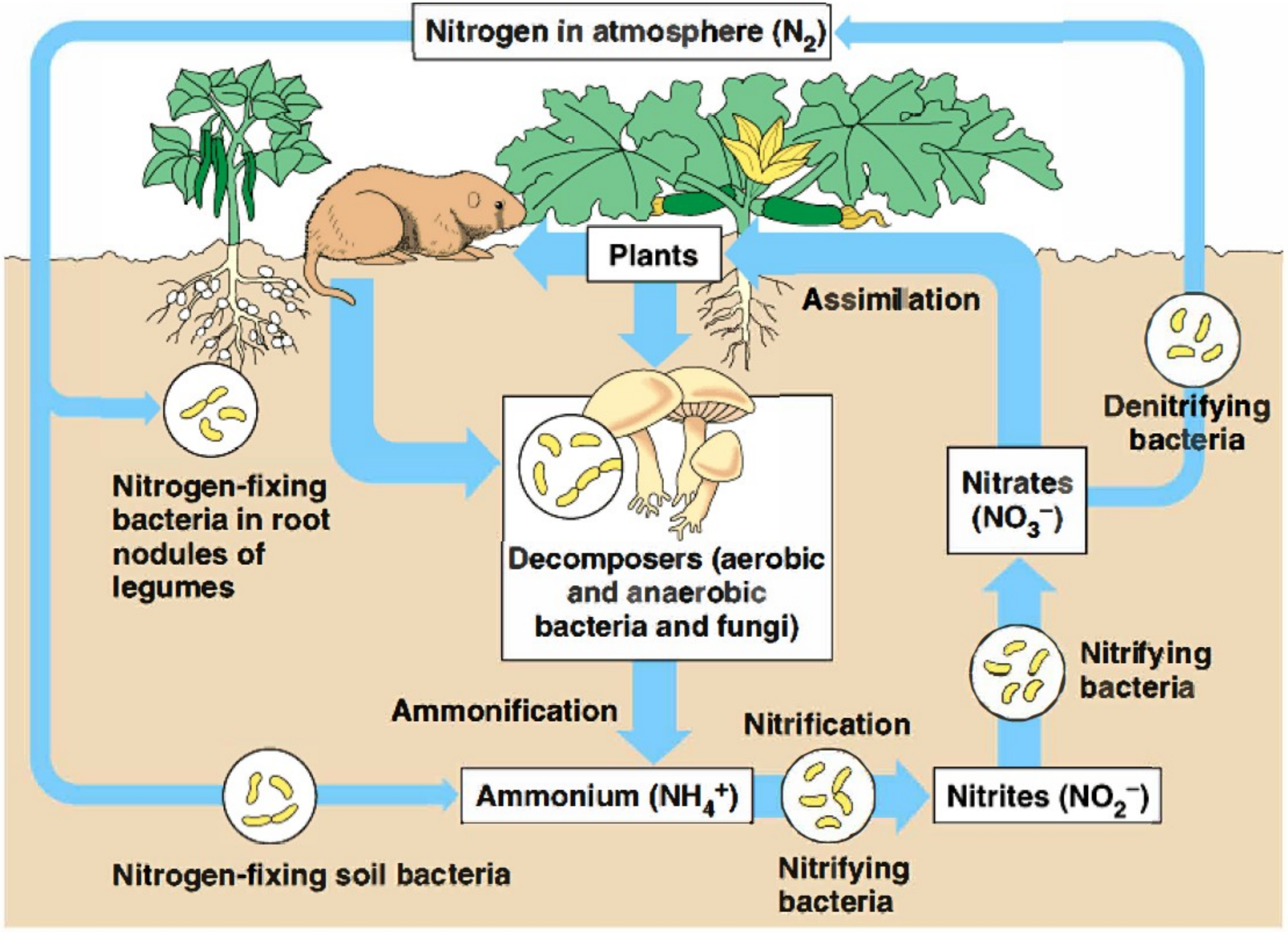
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Ammonification

neralization of organic N in living organisms to form inorganic ammonia or ammonia

$$RNH_2 + 2\ H_2O \rightarrow NH_4^+ + OH^- + ROH$$

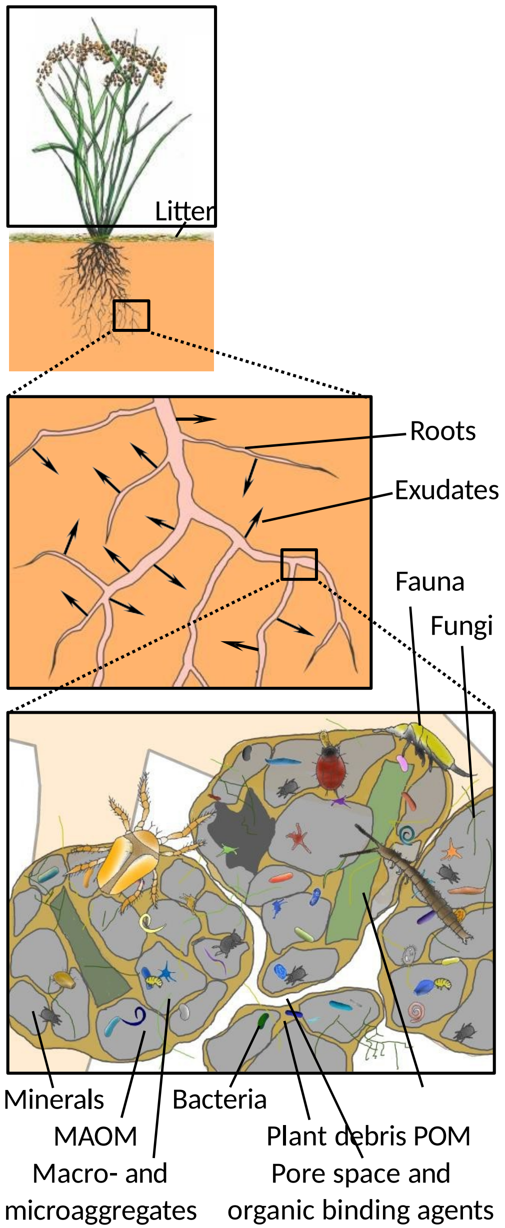
The above equation occurs in two steps:

Step 1: $R\text{-}NH_2 + H_2O \rightarrow NH_3 + R\text{-}OH$

Decomposition of amides and amines ($R\text{-}NH_2$) in amino acids, DN
of dead organisms or feces to NH_3

Step 2: $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$

Reduction of NH_3 to NH_4^+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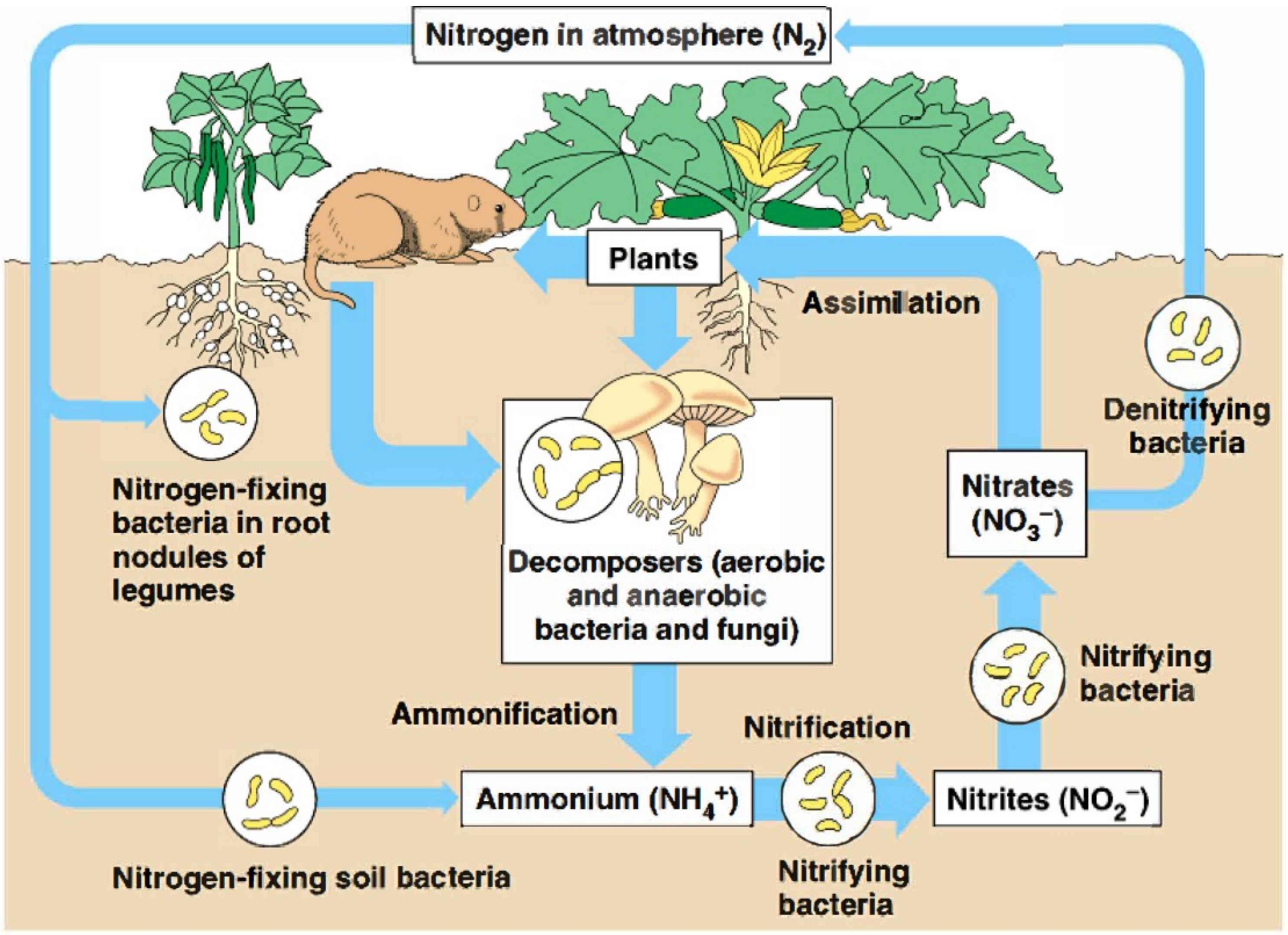
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Nitrification

Ammonia Oxidation

Ammonia-oxidizing Bacteria (AOB)
Ammonia-oxidizing Archaea (AOA)

$$2\,NH_4^+ + 3\,O_2 \longrightarrow 2\,NO_2^- + 4\,H^+ + 2\,H_2O$$ (*Nitrosomonas*, *Comammox*)

Ammonia monooxygenase (AOA)

Nitrite Oxidation

Nitrite-oxidizing Bacteria (NOB)

$$2\,NO_2^- + O_2 \longrightarrow 2\,NO_3^-$$ (*Nitrobacter*, *Nitrospira*, *Comammox*)

Nitrite oxidoreductase

Rate limiters

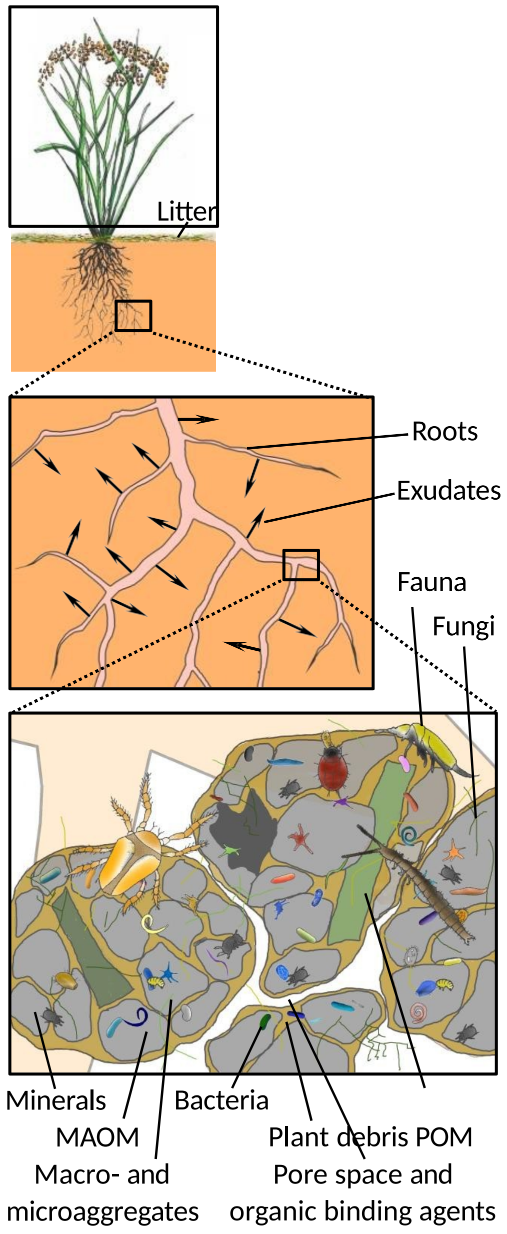
Soil Conditions

- Substrate availability (presence of NH_4^+)
- Aeration (availability of O_2)
- Soil moisture content (availability of H_2O)
- pH (near neutral)
- Temperature

Chemical Inhibition

- Nitrapyrin
- Ammonium thiosulfate

- Nitrification is actually the net result of two distinct processes: the oxidation of ammonia (NH_3) or ammonium (NH_4^+) to nitrite (NO_2^-) by ammonia-oxidizing bacteria (e.g. Nitrosomonas) and the oxidation of nitrite (NO_2^-) to nitrate (NO_3^-) by the nitrite-oxidizing bacteria (e.g. Nitrobacter).
- Nitrification is extremely energetically poor leading to very slow growth rates for both types of organisms.
- Oxygen is required in ammonium and nitrite oxidation; ammonia-oxidizing and nitrite-oxidizing bacteria are aerobes.



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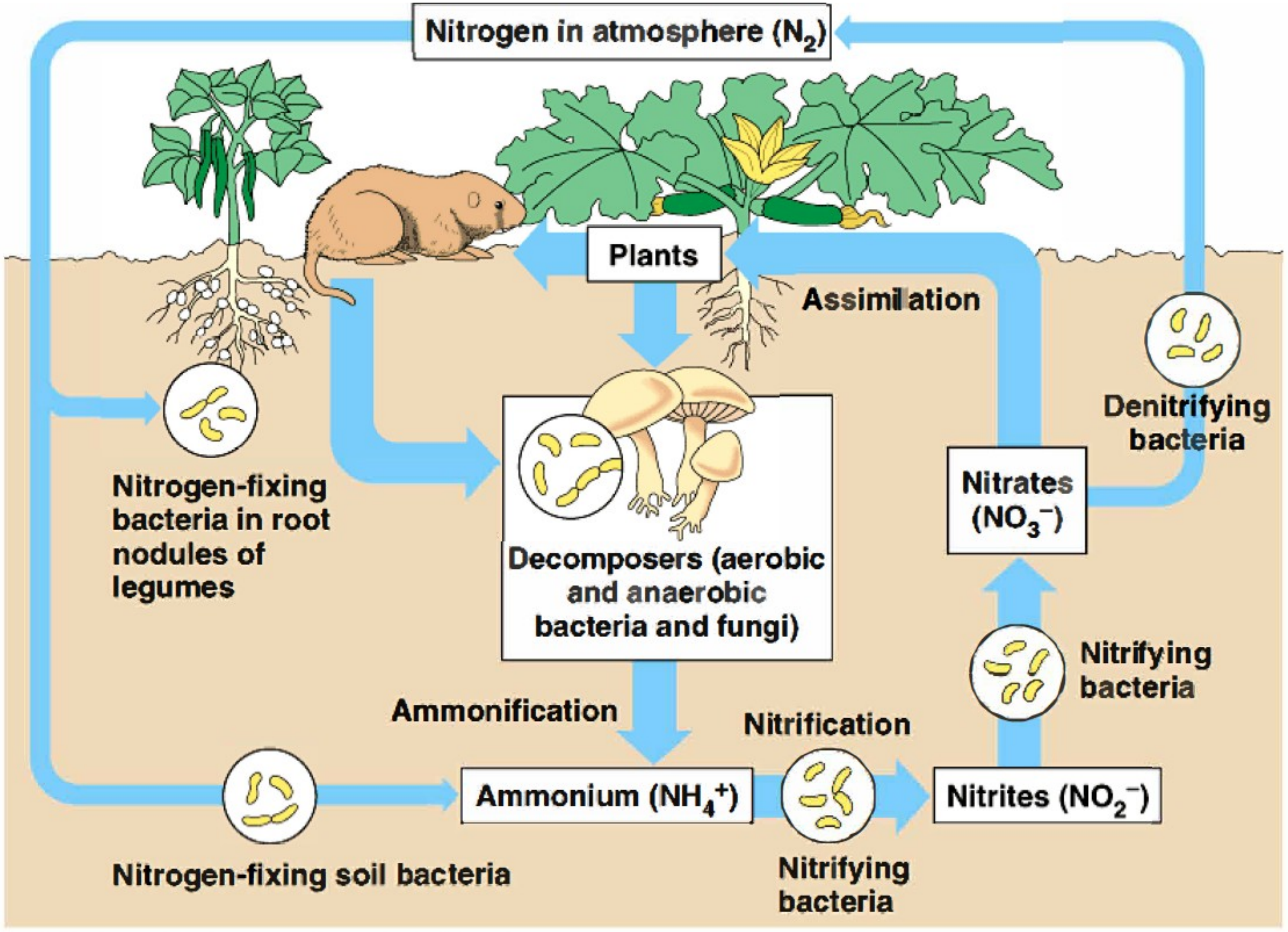

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Denitrification

Reduction of NO_3 to N_2

- $2\ NO_3^- + 10\ e^- + 12\ H^+ \rightarrow N_2 + 6\ H_2O$

- $NO_3^- + 2\ H^+ + 2\ e^- \rightarrow NO_2^- + H_2O$ (Nitrate reductase)
- $NO_2^- + 2\ H^+ + e^- \rightarrow NO + H_2O$ (Nitrite reductase)
- $2\ NO + 2\ H^+ + 2\ e^- \rightarrow N_2O + H_2O$ (Nitric-oxide reductase)
- $N_2O + 2\ H^+ + 2\ e^- \rightarrow N_2 + H_2O$ (Nitrous-oxide reductase)

Formatting:

•Intellectual Merit and Broader Impacts sections are required for both the Personal statement and the Research Plan statement

- Additional subheaders are also allowed

•General formatting reminders:

- Standard 8.5” x 11” page size
- 11pt + Times New Roman font
- 1” margins; no text in headers or footers
- Single-spaced
- PDF format

•References:

- Should include the journal name (abbreviations okay)
- Superscripts in text are fine

Writing Mechanics:

•Use complete sentences and maintain a professional tone

•Check grammar and spelling carefully

Personal Statement:

•Next iteration should aim for the full *three* pages

•Should include both Intellectual Merit and Broader Impacts sections

- Intellectual Merit: The potential for the *student* to advance knowledg
- Broader Impacts: The potential for the *student* to benefit society

•General suggestions for next draft:

- Clarify personal and academic trajectory
- Link experiences to future goals
- Emphasize how background supports proposed research or project
- Include clear next steps toward goals

Research Plan:

•Next iteration should aim for the full *two* pages

•Identify the connection between the reviewed literature and the proposed pro

•Clearly outline the structure of the plan:

- Background
- Aims/Objectives
- Hypotheses (if relevant)
- Methods
- Expected outcomes
- Potential pitfalls (and how they'll be addressed)

•Include in-text citations and a proper reference section

•Should include both Intellectual Merit and Broader Impacts sections

- Intellectual Merit: The potential for the *research* to advance knowled
- Broader Impacts: The potential for the *research* to benefit society

Logic Model

SITUATION

Current Situation

- Farmers and ranchers face increasing challenges from climate change, water scarcity, emerging pests, low prices, and changing regulations
- Regenerative practices have potential to enhance carbon drawdown, soil health, and yield stability, and increase profitability
- We lack understanding of the complex environmental and socioeconomic mechanisms that impact adoption and outcomes, decision support tools, and integration of indigenous knowledge

Desired Vision

- To develop the knowledge, evidence, and predictive tools to enable farmers and ranchers to evaluate the adoption of regenerative practices based on their preferred outcomes

INPUTS

- Multi-disciplinary team of researchers, instructors, management and communication staff, students, and practitioners from leading institutions with demonstrated integrative research, education, and extension experience
- Close partnerships between CSU, MSU, Intertribal Ag Council, and Navajo Nation
- Stakeholder and practitioner networks at farm and regional scales
- Educational programs at university and K-12 level
- Extension programs and networks
- Institutional and infrastructure investments and commitments (CSU Spur campus, Soil Carbon Solution Center, MSU/CSU ag experiment stations)

ACTIVITIES

Research:

- Controlled field experiments
- On-farm case studies throughout producer network
- Socioeconomic analysis and models
- Integrated model development

Education:

- Develop new modular curriculum for secondary education
- Integration of regenerative principles and Indigenous practices into undergraduate courses.

Extension/Outreach:

- Develop innovative learning modules
- New and beginning farmer training
- Field courses

OUTPUTS

Research:

- Mechanistic quantification of Regenerative Agriculture on ecosystem outcomes, including carbon, nutrient and water dynamics (ecosystem services), climate resiliency, and profitability
- Calibration and validation of process-based models that enables system optimization for different outcomes at farm and regional scales
- Socioeconomic cost-benefit models with social, cultural, and economic barriers and trade-offs

Education:

- Teaching modules and curricula
- Student participation in research and extension

Extension/Outreach:

- Accessible information for technical assistance/training (learning modules, fact sheets, videos)
- Evidence-based decision-support tools

Assumptions – Increased scientific validation of RA outcomes and translation of science findings is insufficient to accelerate adoption of best practices. Regenerative principles must be implemented through different practices depending on context-specific factors.

Internal/External Factors – Federal, state, and tribal policy changes; producer and food consumer perception of "regenerative"; hype and marketing of outcomes that lack scientific evidence could all influence adoption of regenerative principles.