Microbial processes in soil I

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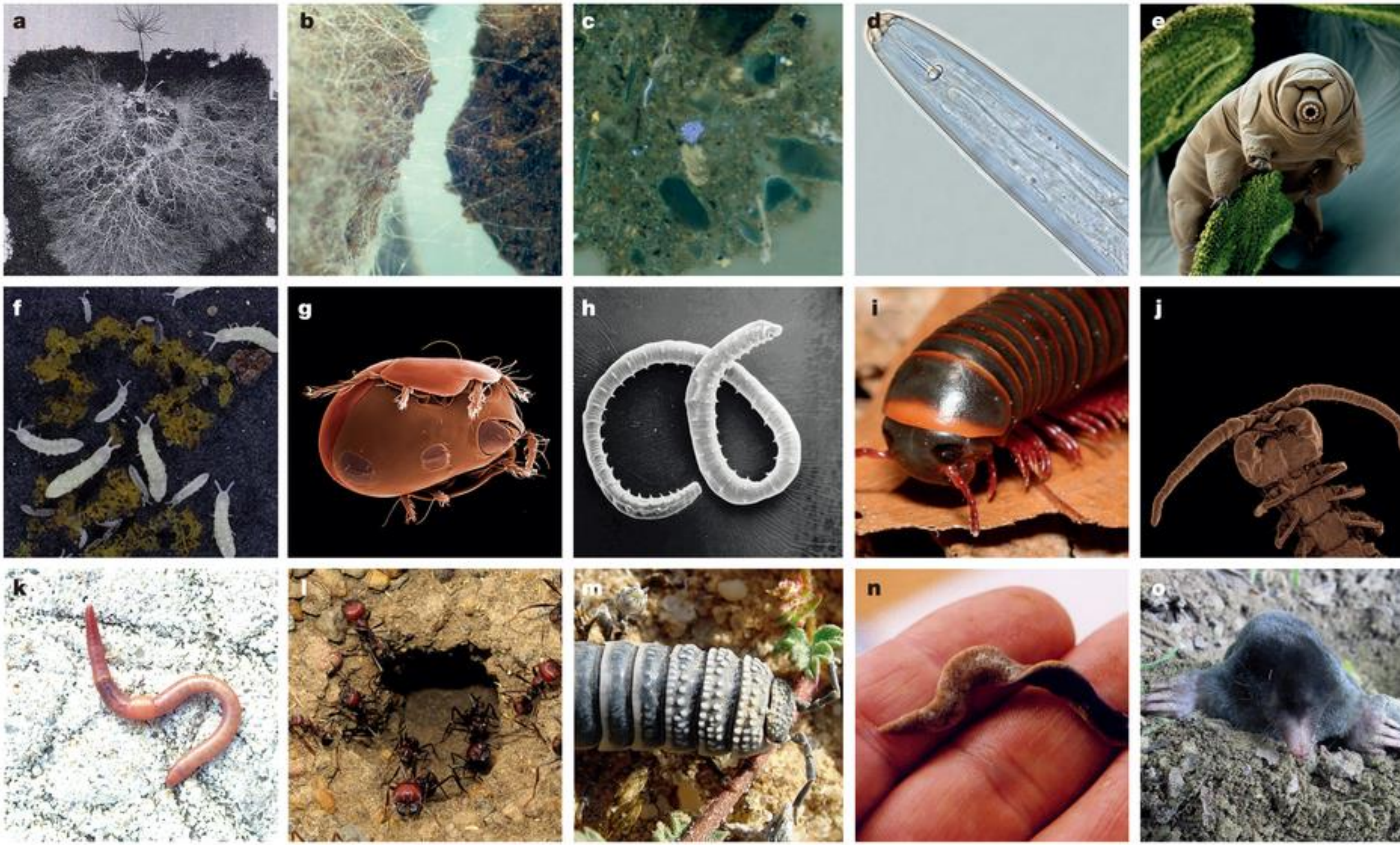
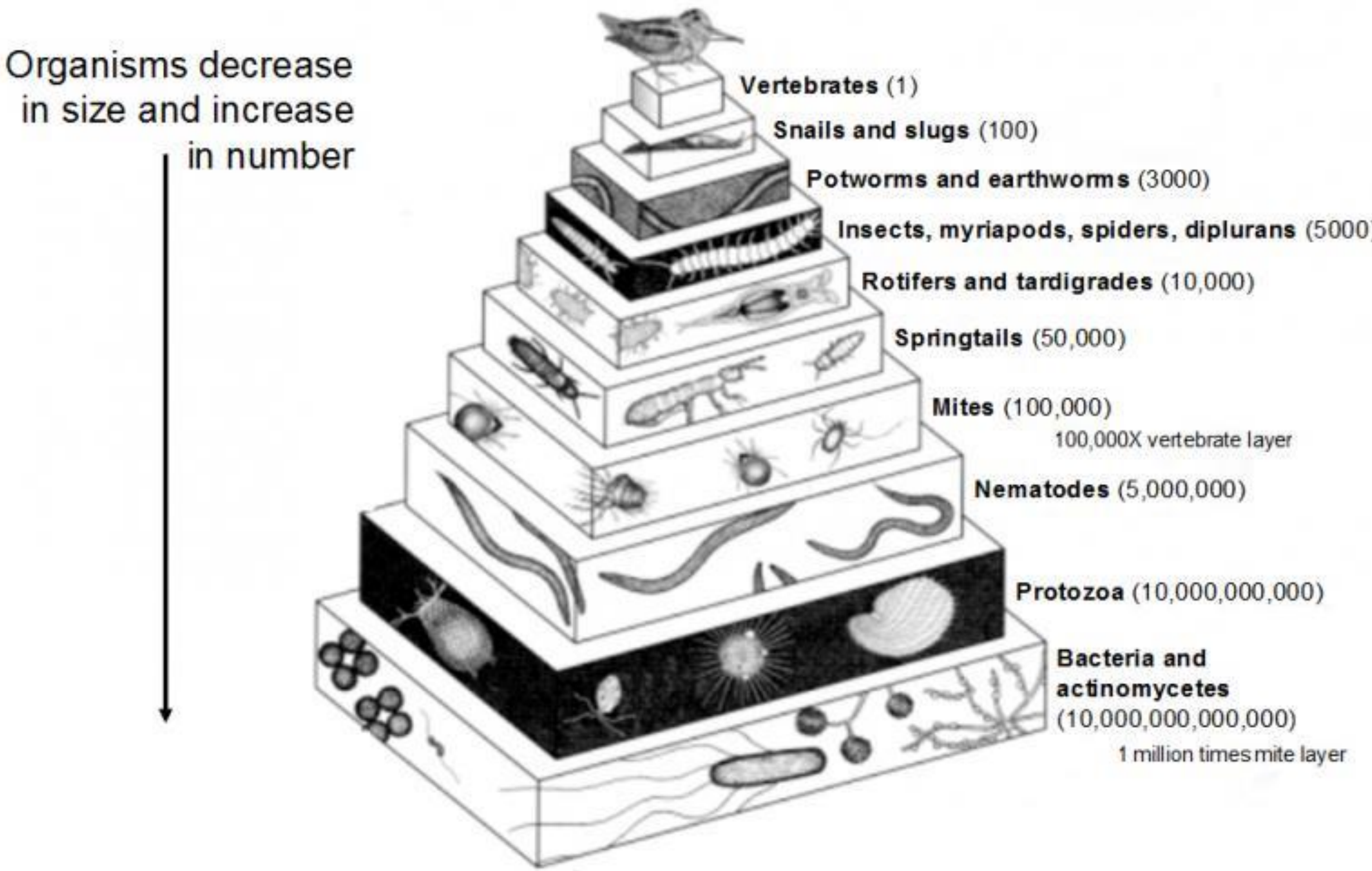
What you already know: SOIL IS ALIVE



https://www.google.cz/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&*cad=rja&uact=8&ved=0ahUKEwiG1caZi_POAhXsHJoKHdzkDSoQjRwIBw&url=http%3A%2F%2Fwww.nature.com%2Farticles%2Fnature13855&psig=AFQjCNEZ9e0OarZ0InbvtqwHwtHpLTOEng&ust=1472988278889510*

What you already know: in one square meter of soil…



http://squqs.com/sites/default/files/u122/oneMeterSoil.jpg

Microbial processes in soil

Why we are so interested in soil microbial processes ?

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What you are going to learn:

http://www.soil-net.com

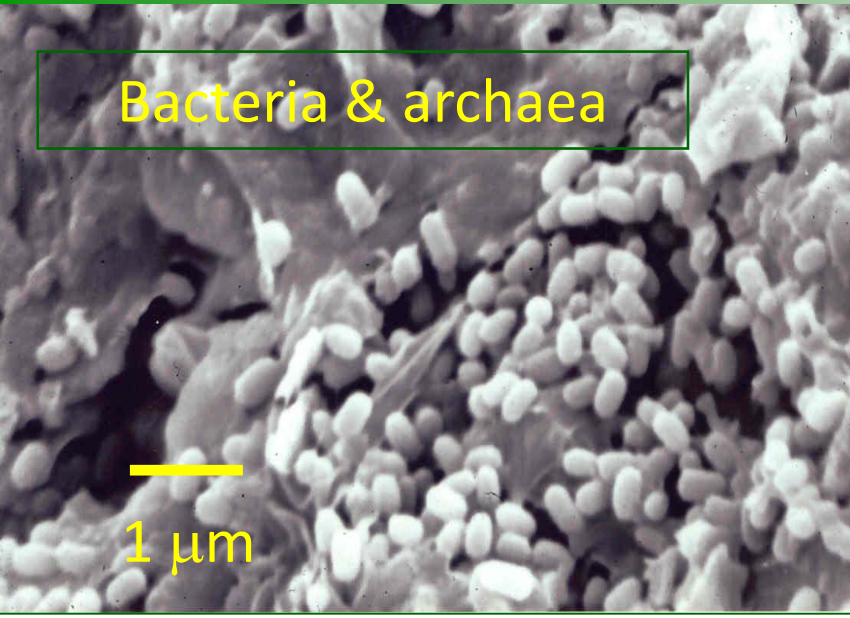
there are more living organisms in a teaspoon of healthy soil than there are people on Earth and most of them are microbes

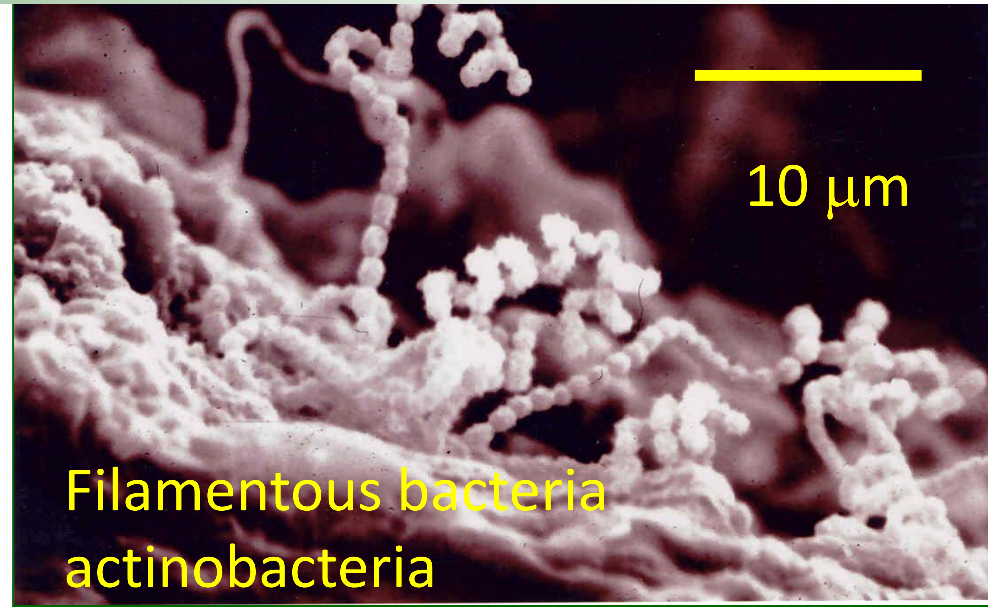
&

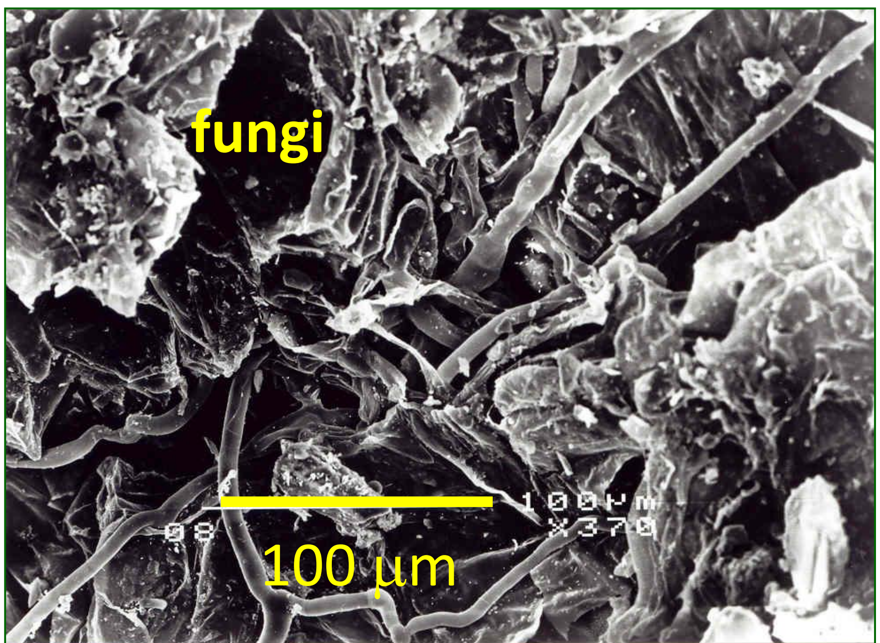
90 % of carbon and nutrient transformations are carried out by microbes

… and when you want to understand them, you should know a little bit about microbial functioning

which **microbes** are in the soil







Source: https://www.nrcs.usda.gov

Outlines

Lecture I:

Brief look at:

- **microbial physiology**
- **microbial stoichiometry**
- **soil enzymes**
- **effect of environmental factors on processes**

Lecture II:

- **C transformations**
- **N transformations**
- **P transformations**

Brief look at microbial physiology

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Microbes *(bacteria, archaea and fungi)* grow and

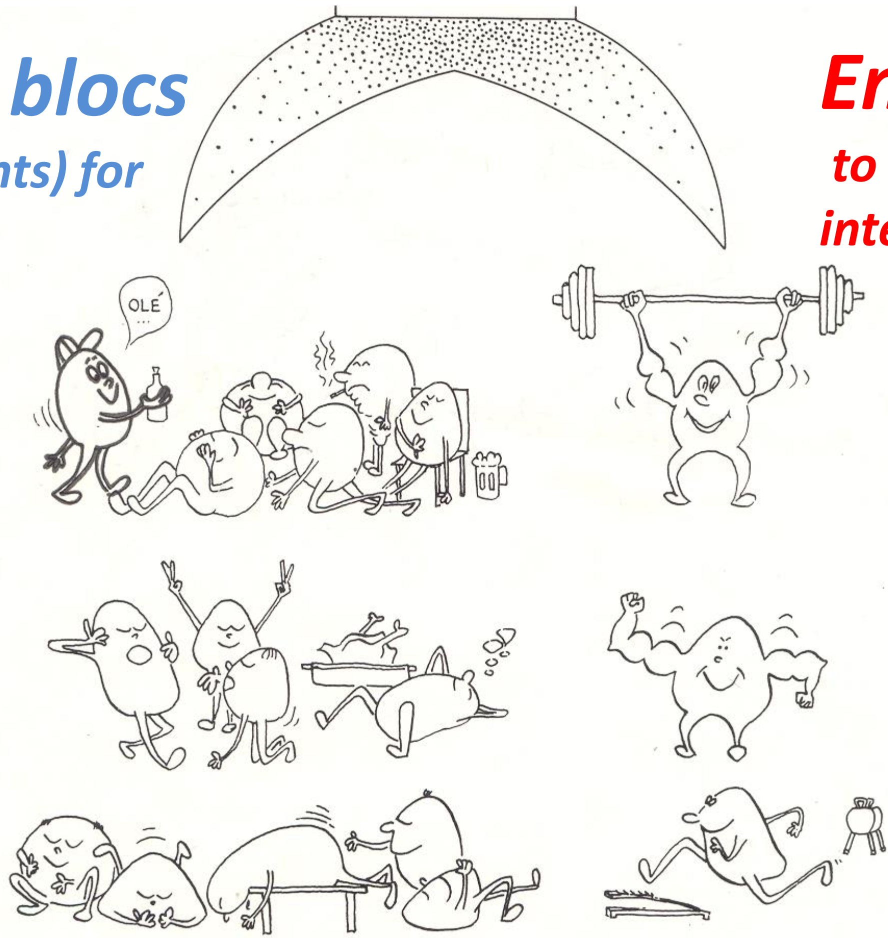
they need to get

Building blocs

(C and nutrients) for growth

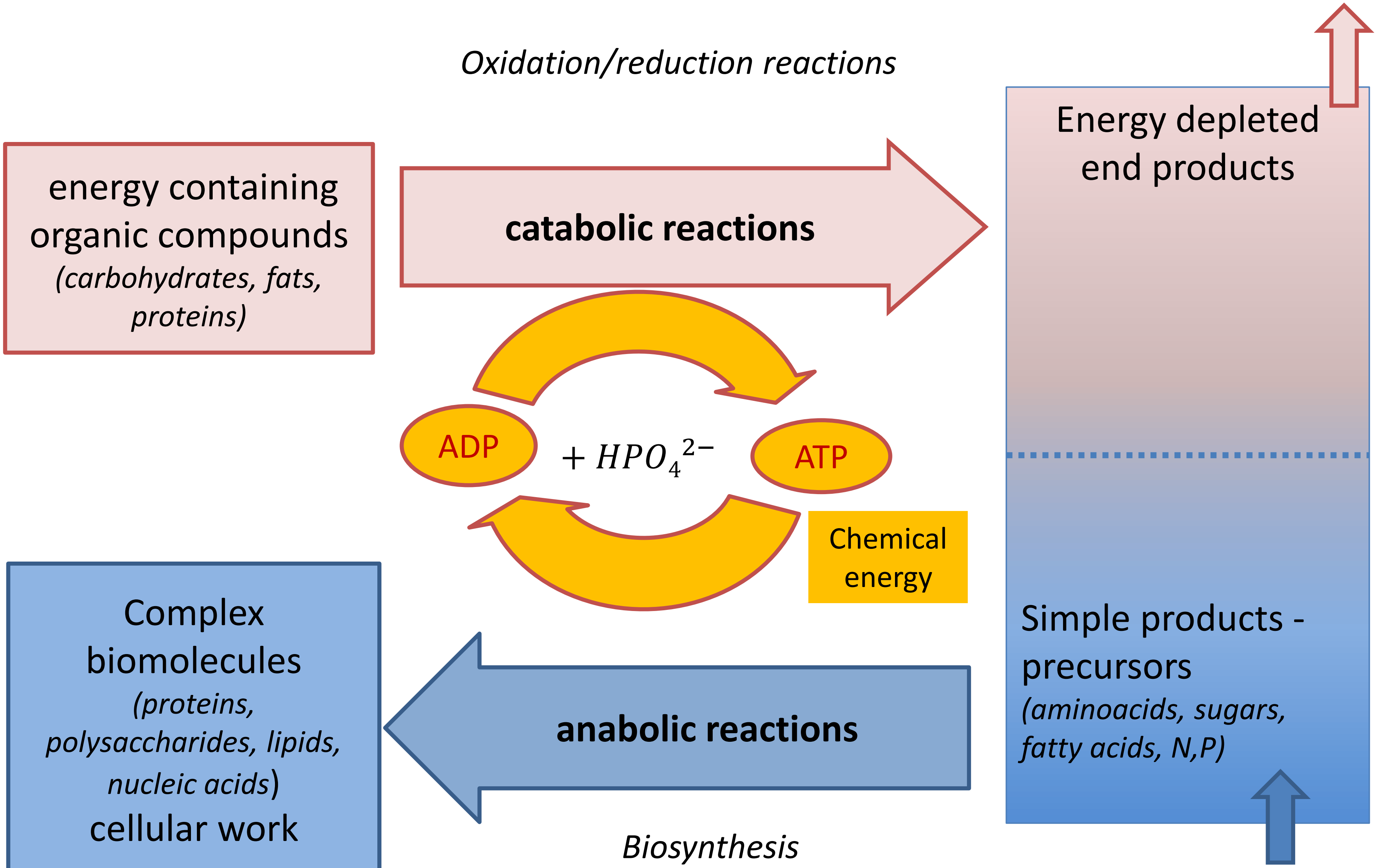
Energy

to move, keep cellular integrity, metabolize…

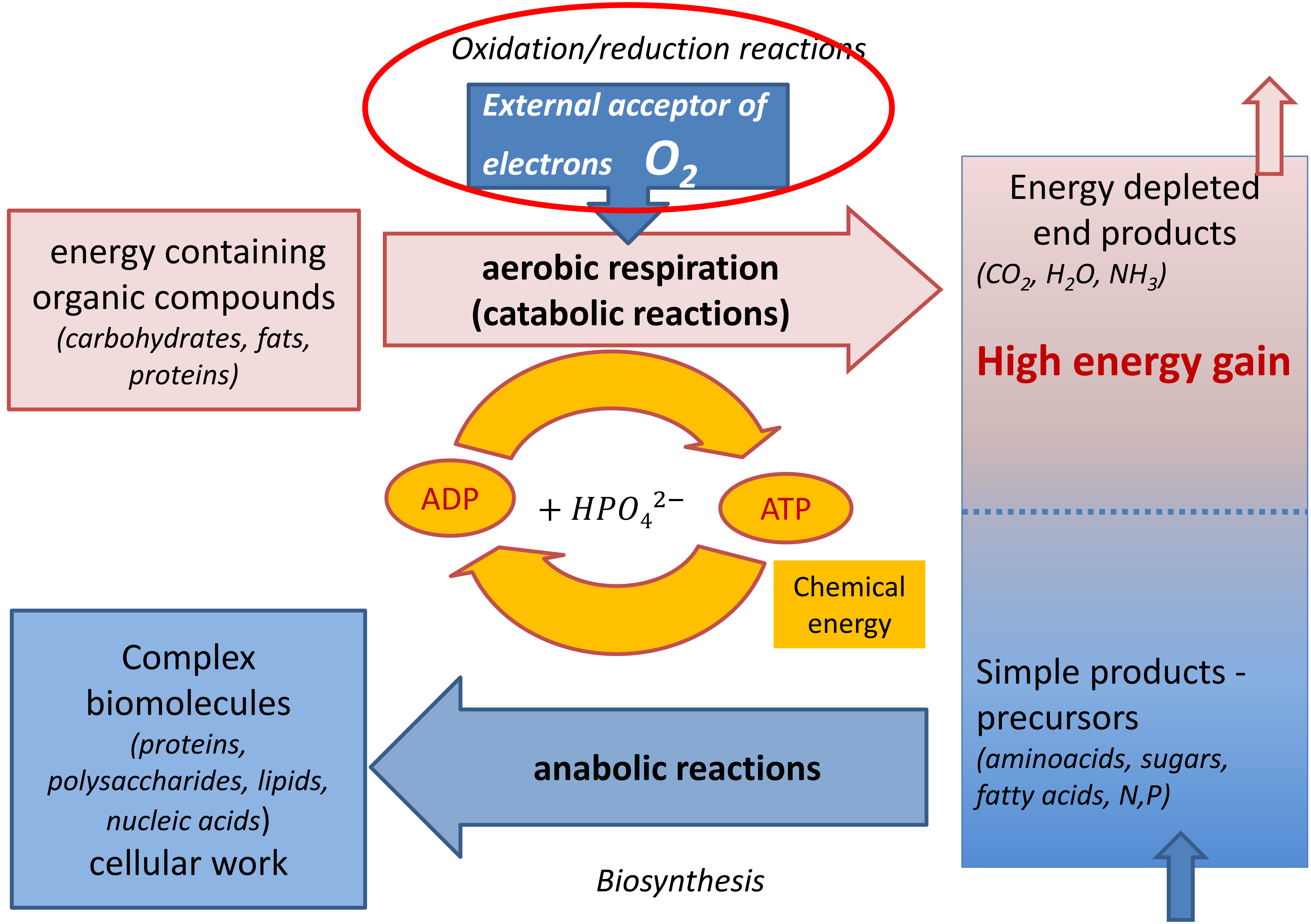


…and they run soil microbial processes whether they want or not

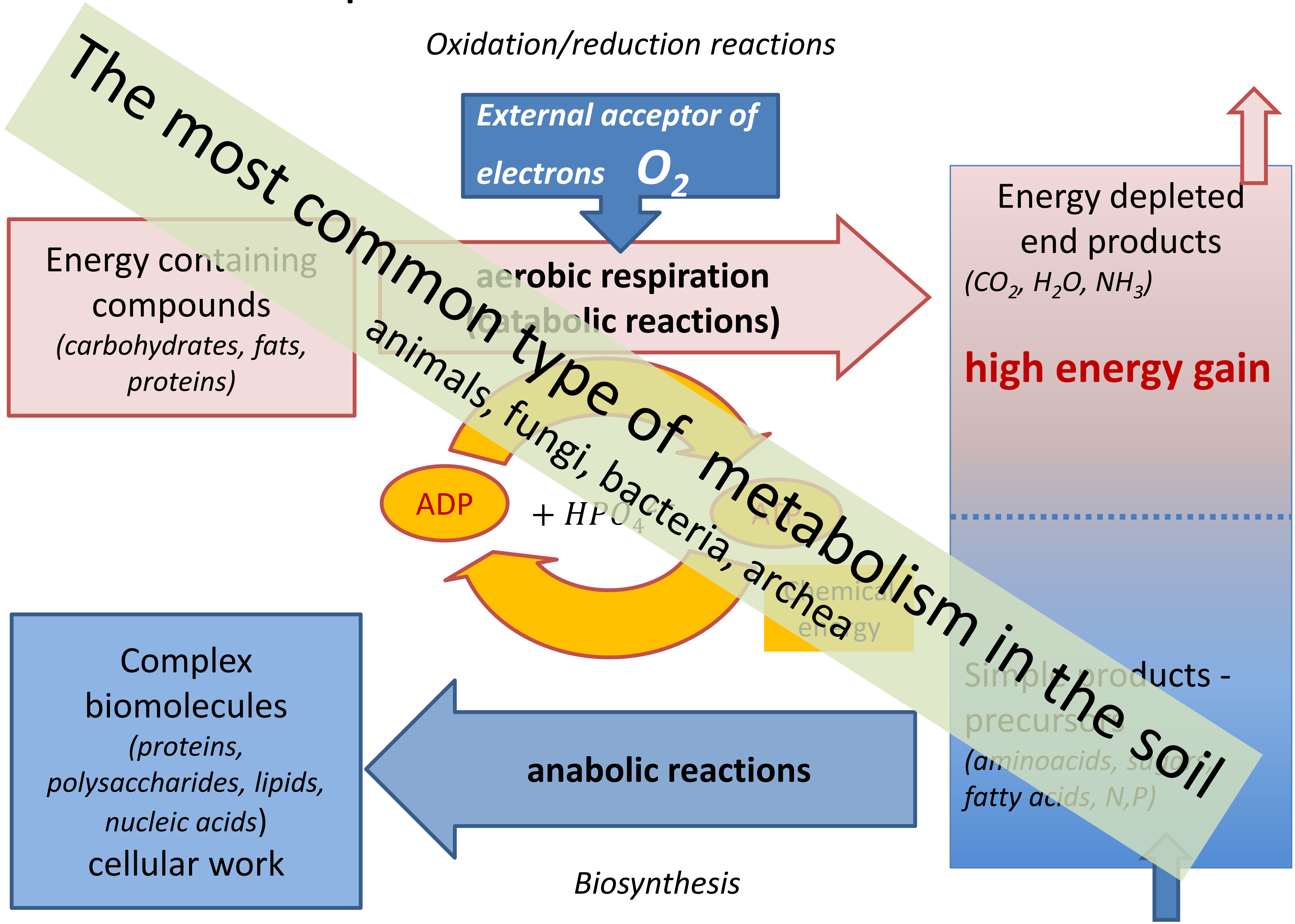
Heterotrophic metabolism



Heterotrophic **aerobic** metabolism



Heterotrophic **aerobic** metabolism



Everything would be so easy, if all soil microbes have "simple and invariable" aerobic heterotrophic metabolic pathways …..

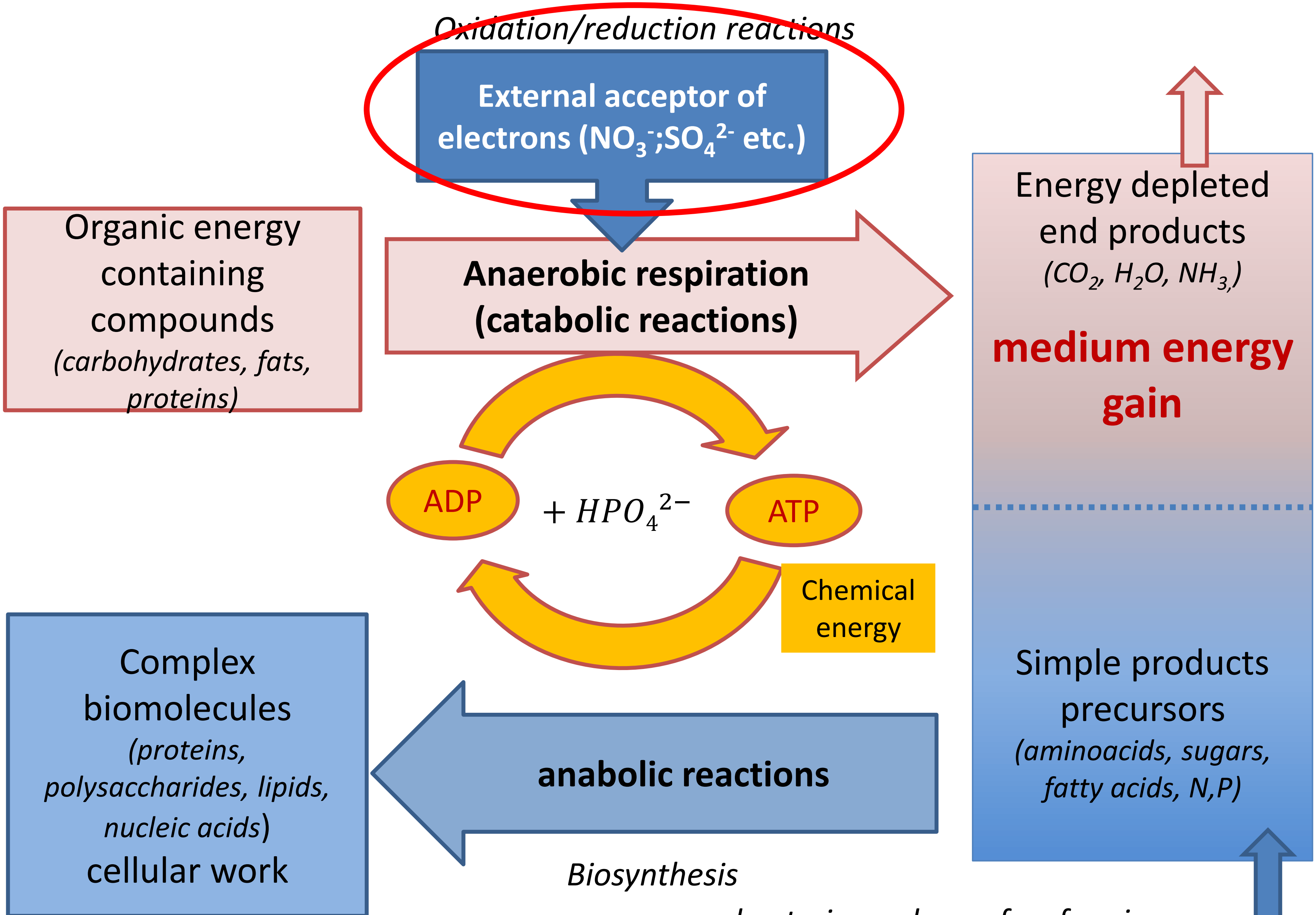
Everything would be still easy, if microbial community is composed only from fungi and not from prokaryota ….

… but we deal with the soil which ….

- **would not be properly functioning**
- **C and nutrient transformation could not be completed**
- **plants would suffer of nutrient deficiency**

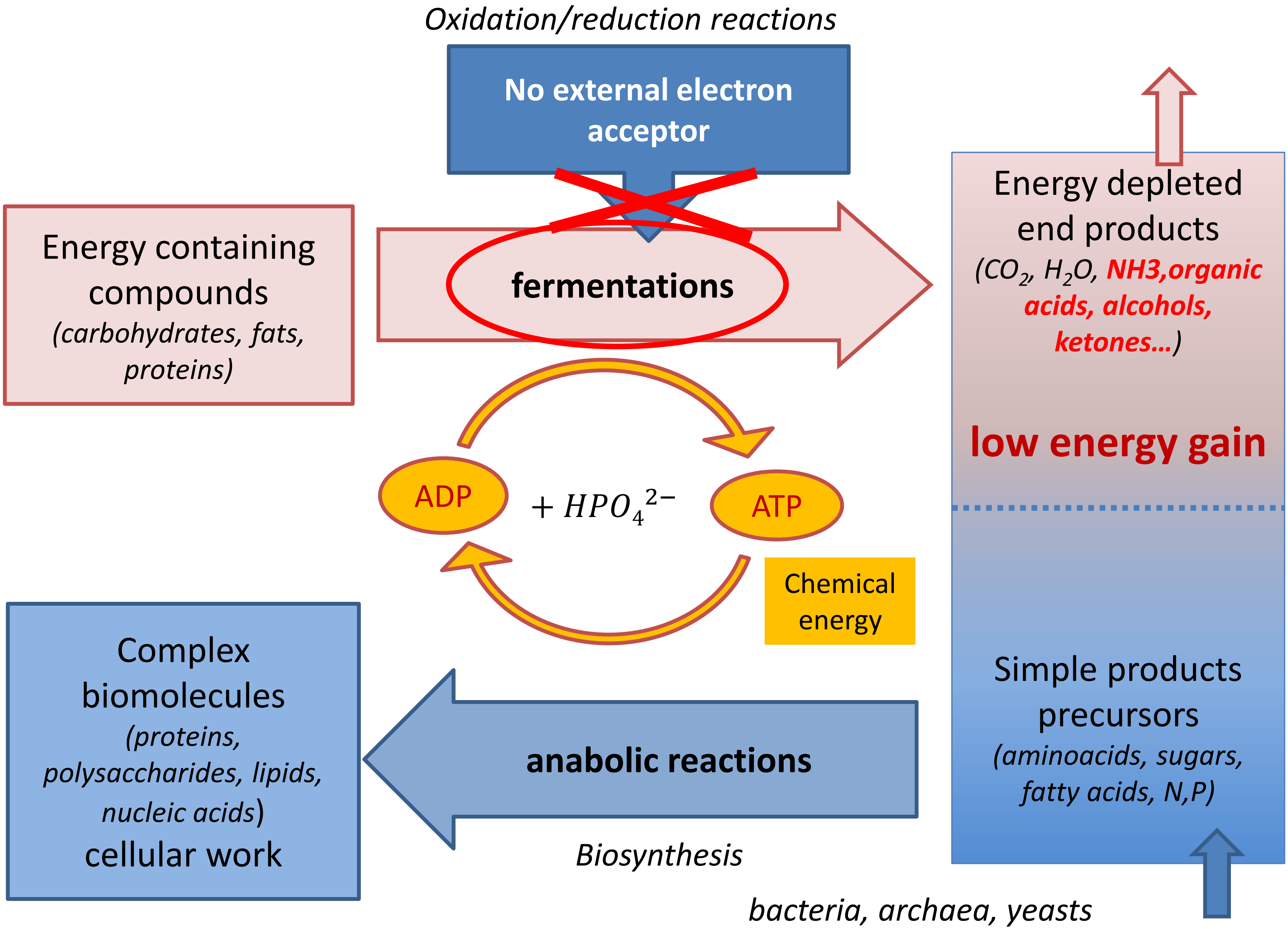
Soil needs prokaryota (bacteria and archaea) with their **metabolic heterogeneity and flexibility**

Heterotrophic **anaerobic** metabolism **(1)**

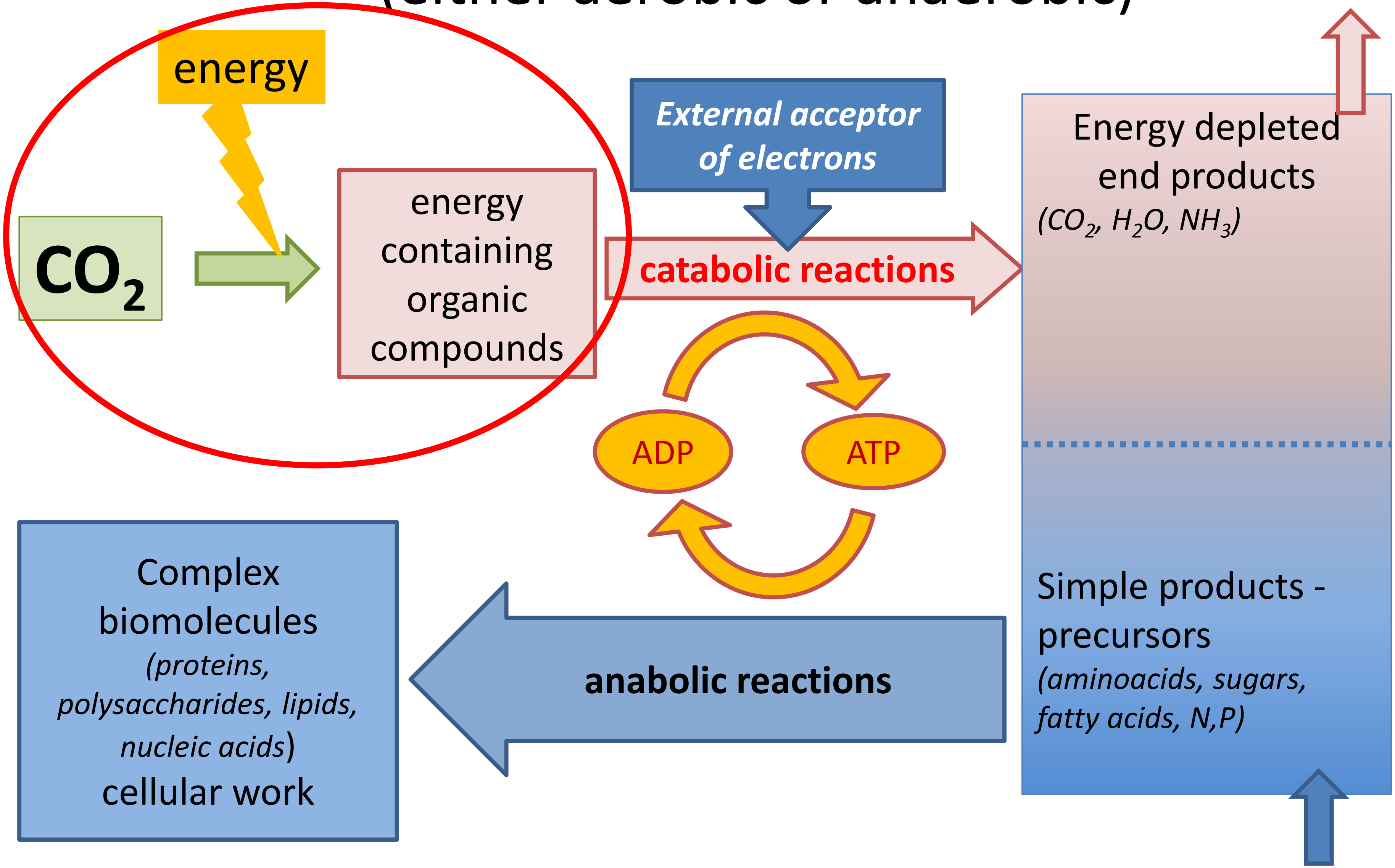


bacteria, archaea, few fungi

Heterotrophic **anaerobic** metabolism **(2)**

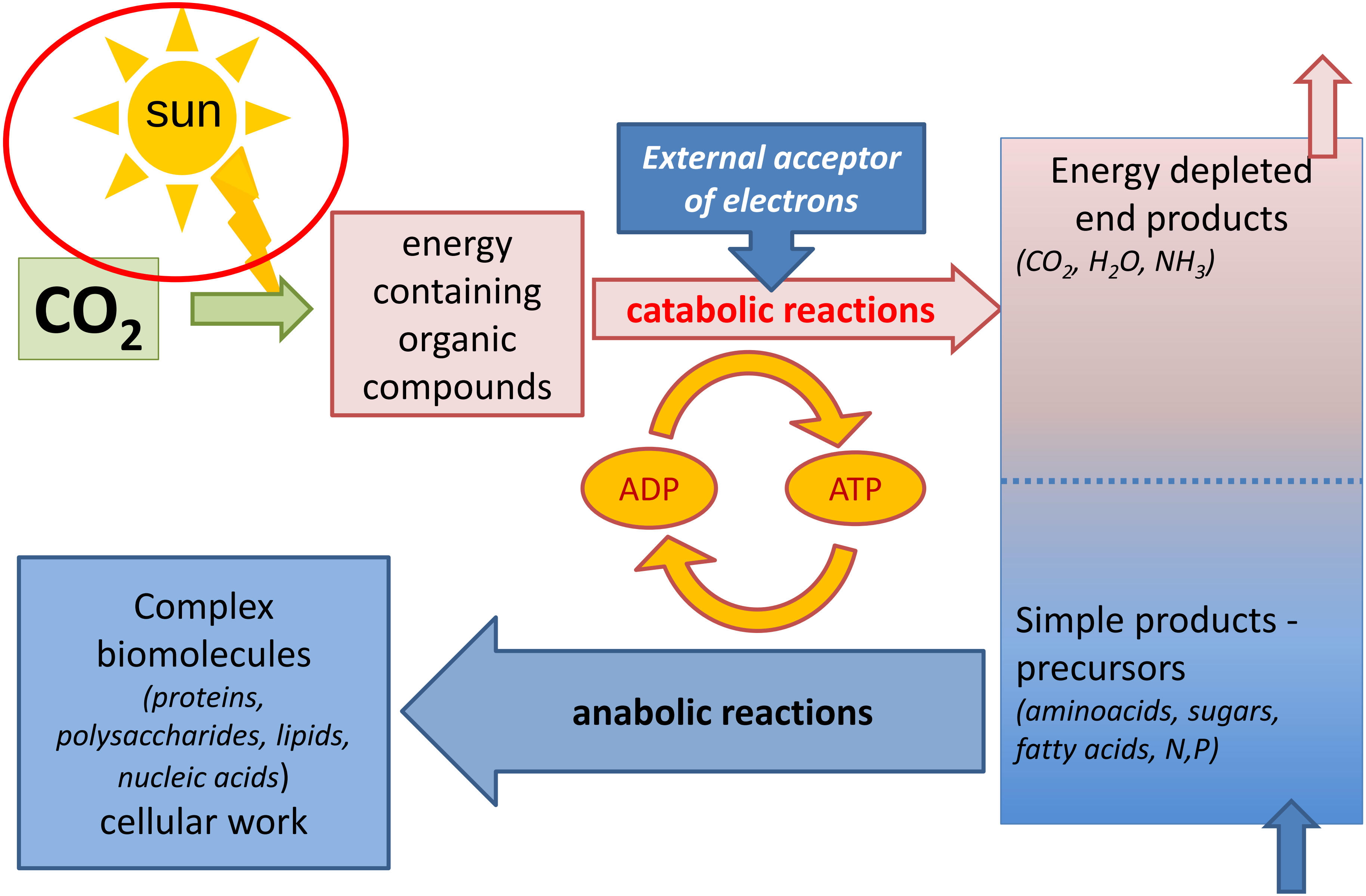


Autotrophic metabolism (either aerobic or anaerobic)

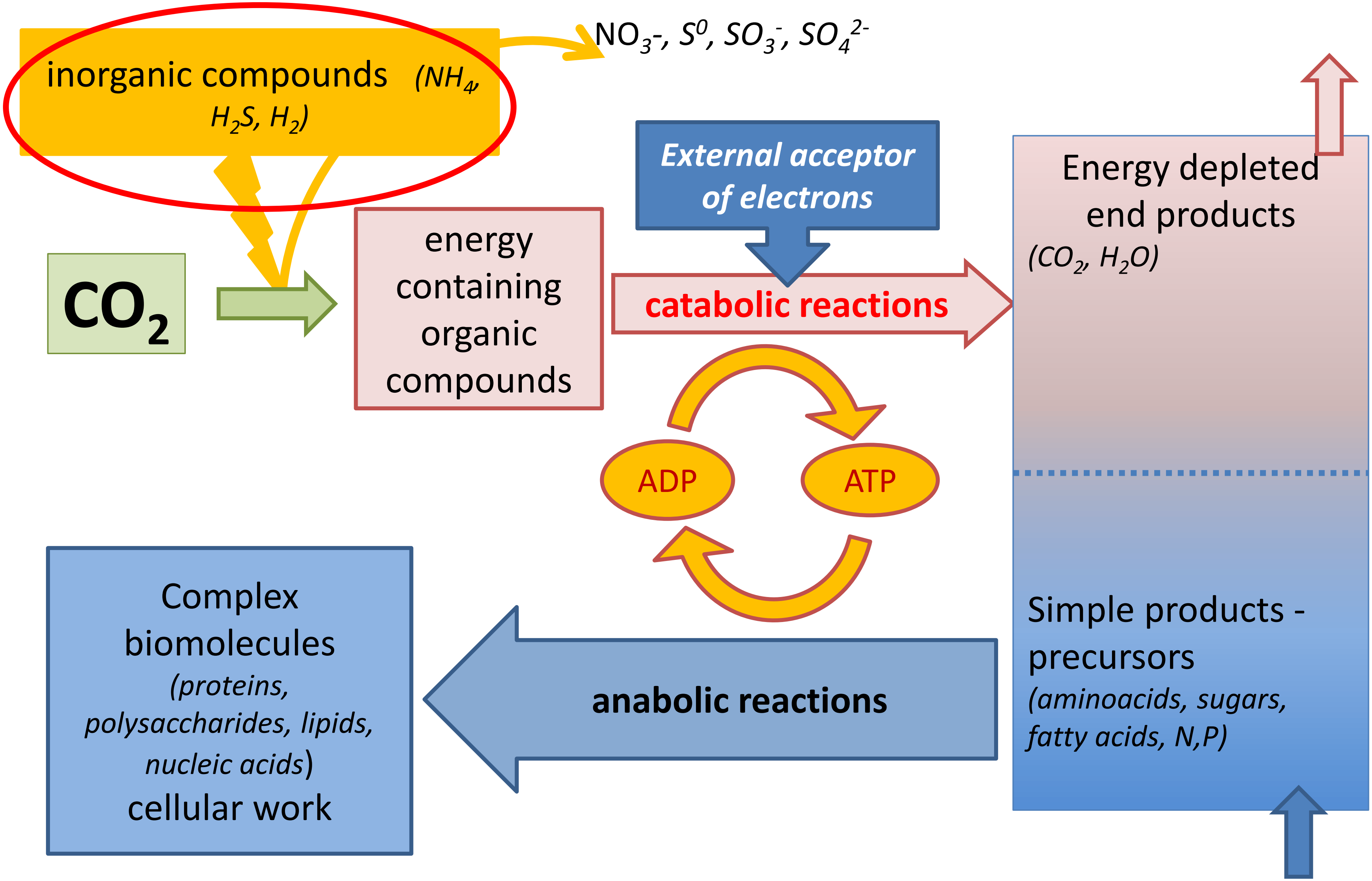


plants, bacteria, archaea

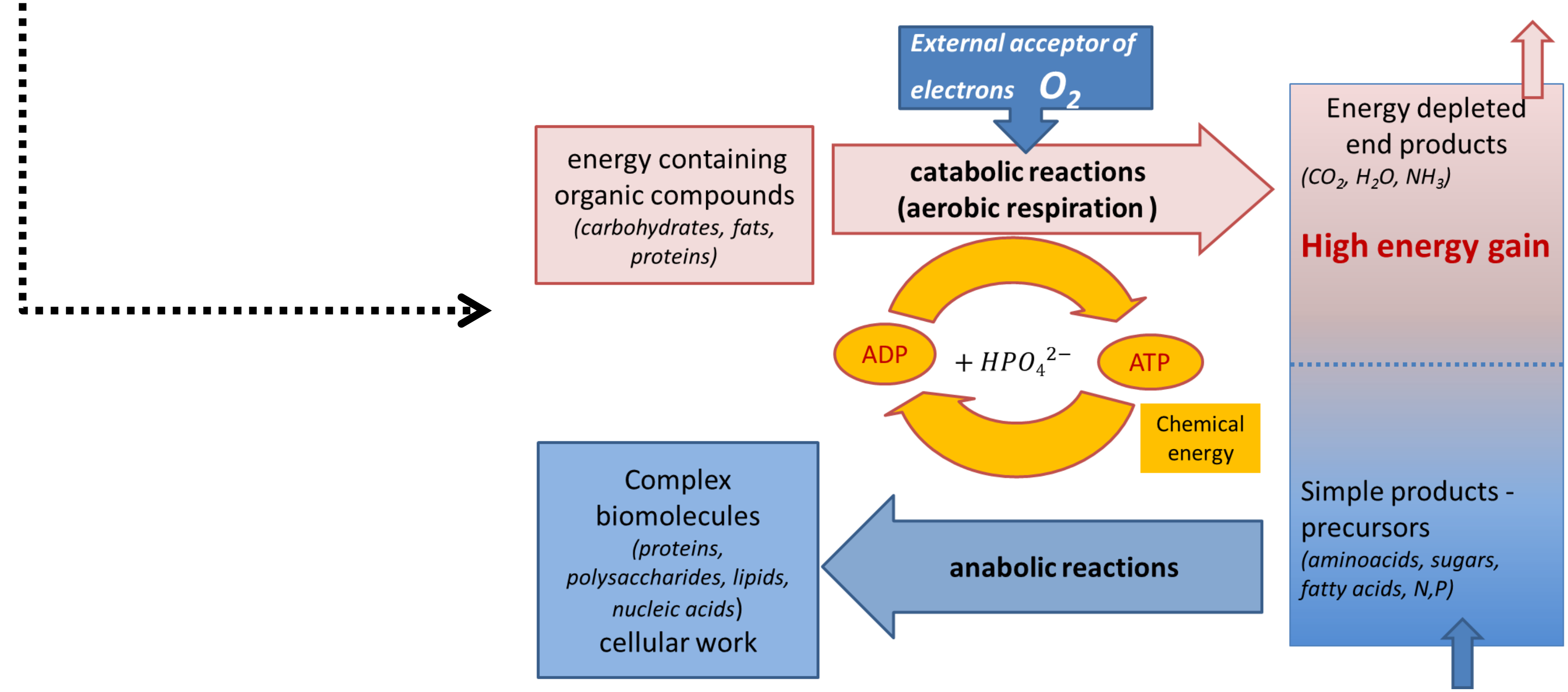
Photoautotrophic metabolism



Chemoautotrophic metabolism

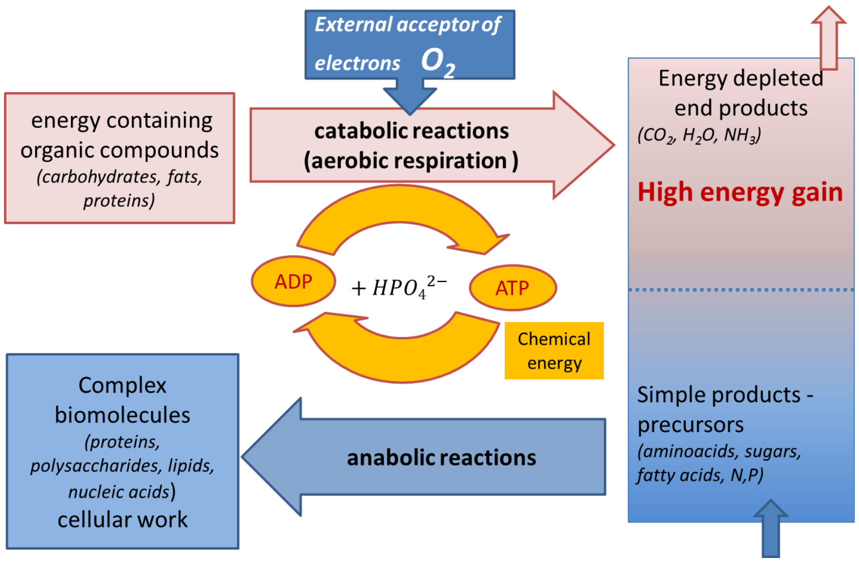


- **Soil microbes run plenty metabolic pathways which give them high flexibility and allow them to decompose huge variety of compounds in highly variable conditions**
- **Aerobic heterotrophs are the most abundant microbes in soil**

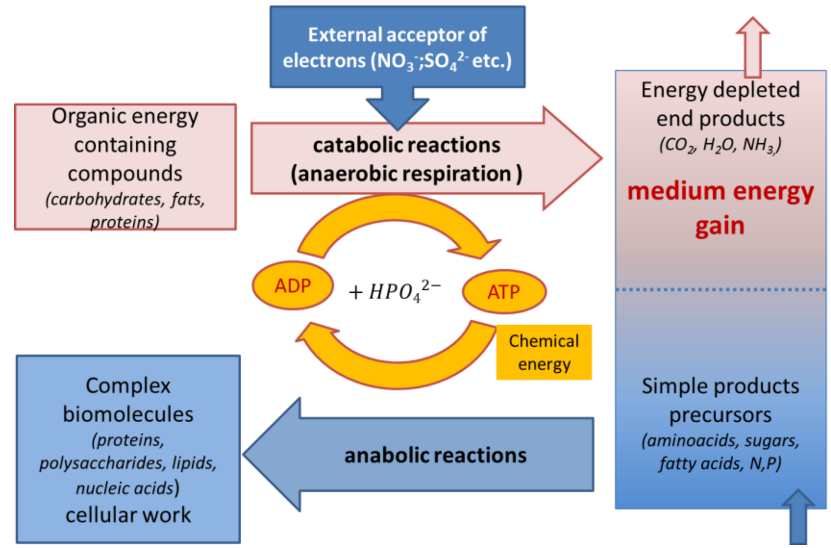


What is the difference between respiration (aerobic/anaerobic) and fermentations?

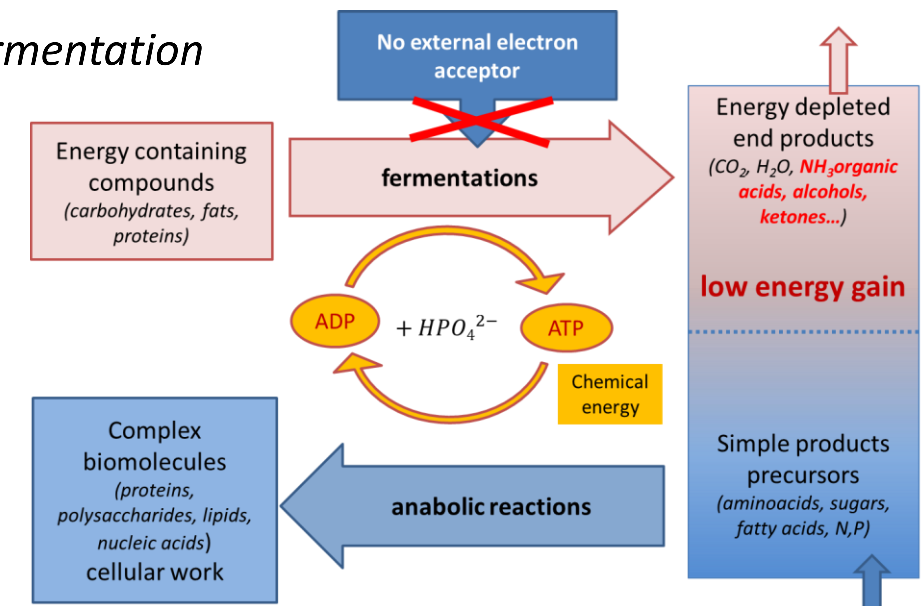
aerobic respiration



anaerobic respiration



fermentation



What is the difference between respiration (aerobic/anaerobic) and fermentations?

respirations

- Efficient metabolic pathway
- Full oxidation of polymers and monomers to CO_2 by <u>one cell</u>

fermentations

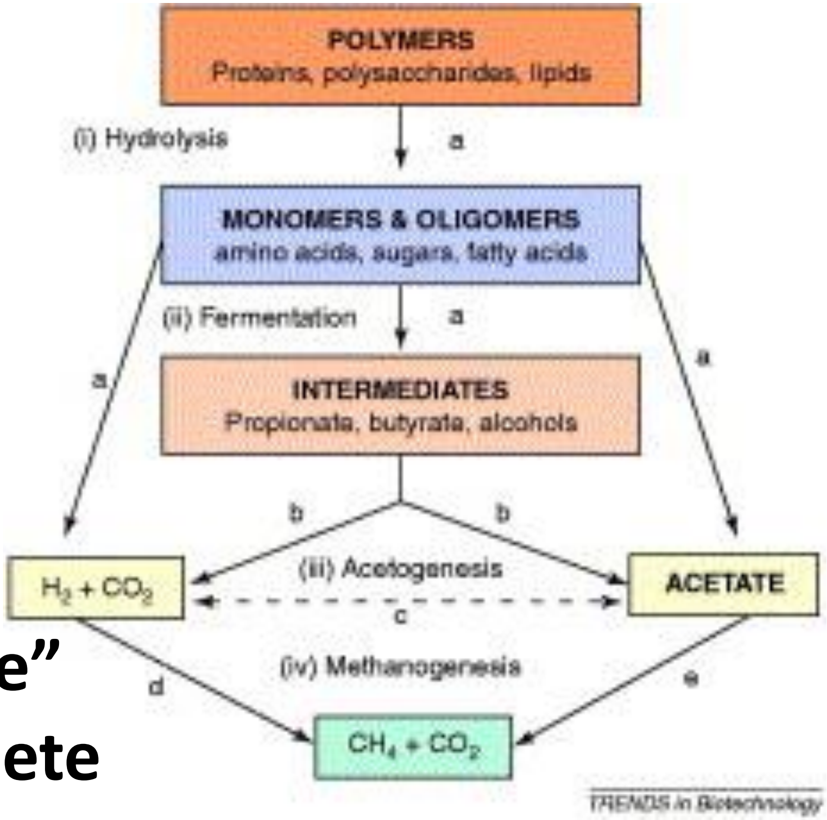
- Inefficient metabolic pathway
- Besides CO_2 a lot of organic byproducts are released to the soil and they must be mineralized by several microbial groups in <u>sequential steps</u>

↓

anaerobic food chain

Anaerobic food chain

Angenent et al. 2004 Trends in Biotechnology 22 477-485

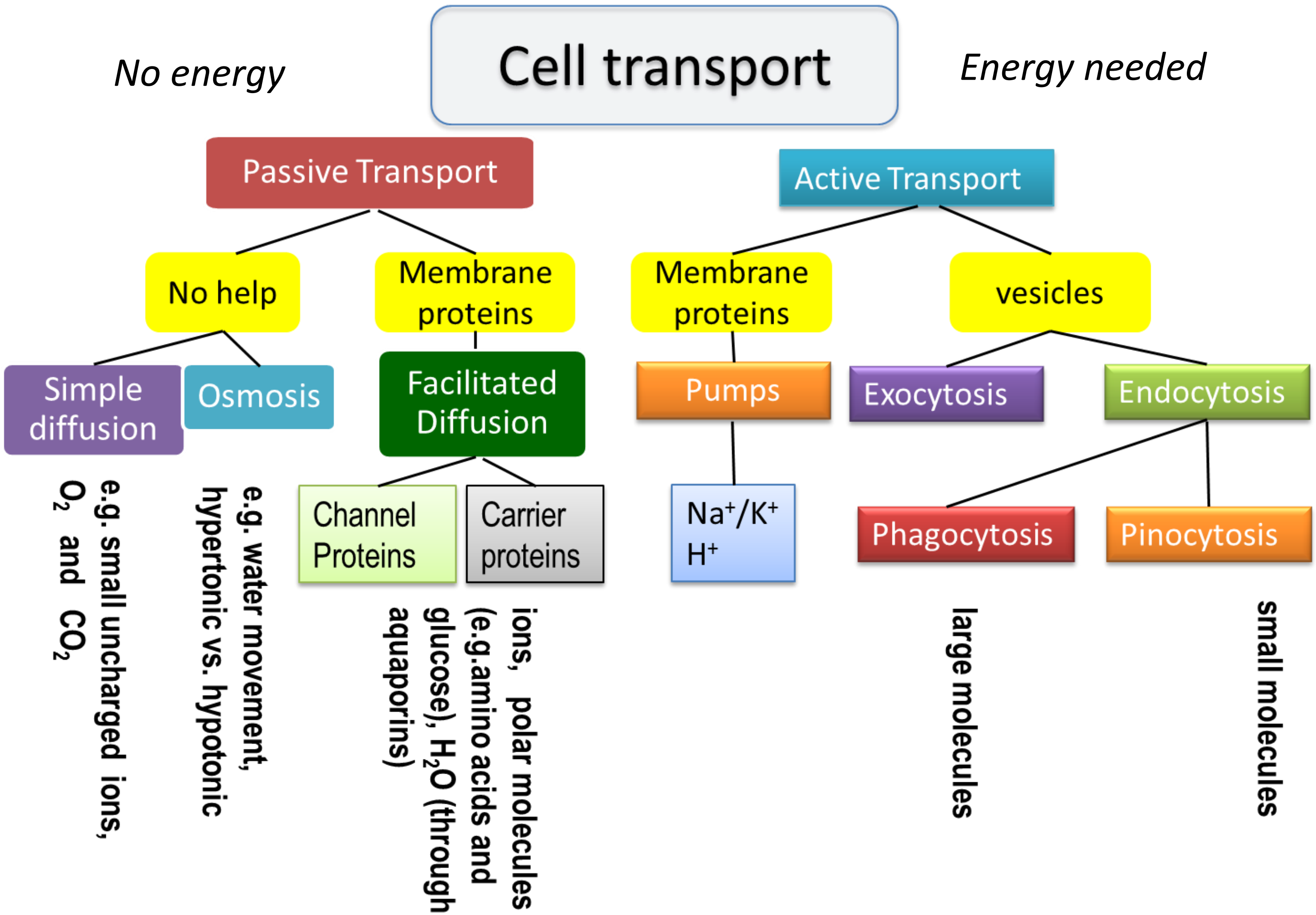


Many microbes must "collaborate" in anaerobic food chain to complete mineralization of organic matter, only few of them can decay complex compounds.

anaerobic soils are more sensitive to disturbance than aerobic soil & organic matter accumulates there

Microbes are osmotrophs

(they must transport compounds across membranes)



the most important points:

- microbes transform/decompose organic compounds as they need to get C, nutrients and energy to growth
- there is high amount of metabolic pathways in the soil which gives microbial community high flexibility
- proper functioning of soil depends on this metabolic flexibility and diversity
- soil aeration has huge effect on microbial community and, therefore, on organic matter transformation
- microbes are osmotrophs

composition of microbial cell & ecological stoichiometry

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ECOLOGICAL STOICHIOMETRY

- Nutrient requirements are driven by the elemental composition of biomolecules in the cell
- Organism growth is limited by nutrients, and they take up (and excrete) nutrients preferentially to get the ratios they need
- Different nutrients are limited by different processes. *(e.g.N is widely available in the atmosphere, but energetically costly to acquire. P is rarer and locked up in mineral deposits.)*
- Ecosystems vary widely in the nutrients available, and ecological structure is driven partly by these availabilities and how they propagate through physiology and trophic structure

MOLECULAR & ELEMENTAL COMPOSITION OF CELL

Bacterial cell

30% chemicals

70% H_2O

Ions, small molecules 4%

Phospholipids 2%

DNA 1%

RNA 6%

Proteins 15 %

Polysaccharides 2%

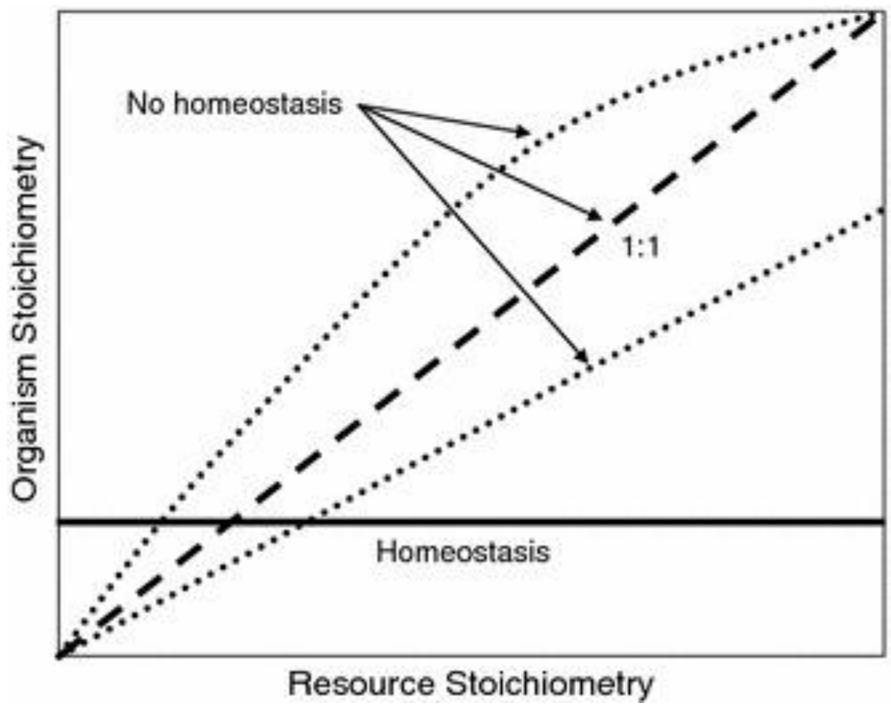
(Phospholipids, DNA, RNA, Proteins, Polysaccharides: macromolecules)

Essential elements as a percent of dry cell weight

C	50%	**P**	2.5%
O	17%	**S**	1.8%
N	13%	**Se**	<0.01%
H	8.2%		

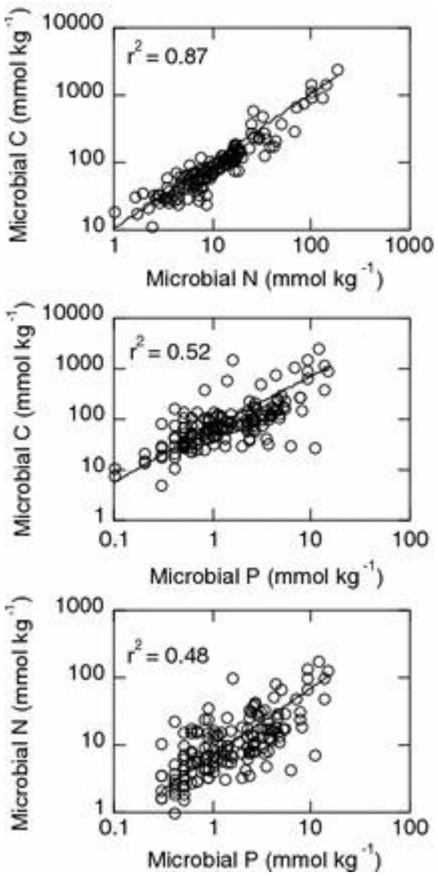
Microbes are homeostatic

and it affects resource to consumer stoichiometry (also nutrient excess/deficiency - nutrient treshold ratio)



Potential patterns relating resource to consumer stoichiometry. The stoichiometry of homeostatic organisms (solid line) is strictly defined, and changes in resource stoichiometry do not influence organism stoichiometry. The stoichiometry of non-homeostatic organisms may match resource stoichiometry in a 1:1 relationship (large dashes) or in a relationship (small dashes) that diverges from the 1:1 line (Adapted from Sterner and Elser 2002) *Cleveland & Liptzin 2007 Biogeochemistry 85; 235-262*

Relationships between C, N and P in the soil microbial biomass is not changing



Microbes need to get food with adequate amount of C, N and P to be able to build biomass of definite stoichiometry (C/N; C/P; N/P)

Cleveland & Liptzin 2007 Biogeochemistry 85; 235-262 resource (SOM) *versus* microbial stoichiometry

Soil organic matter (SOM)

C : N : P = 287 : 17 : 1 (Xu et al. 2013)

1 : 0.06 : 0.004 *(per mol C)*

Soil microbial biomass

C : N : P = 42 : 6 : 1 (Xu et al. 2013)

1 : 0.14 : 0.023

How many mol C of SOM should soil microbe consume to get enough **nitrogen** to build up biomass?

How many mol C of SOM should soil microbe consume to get enough **phosphorus** to build up biomass?

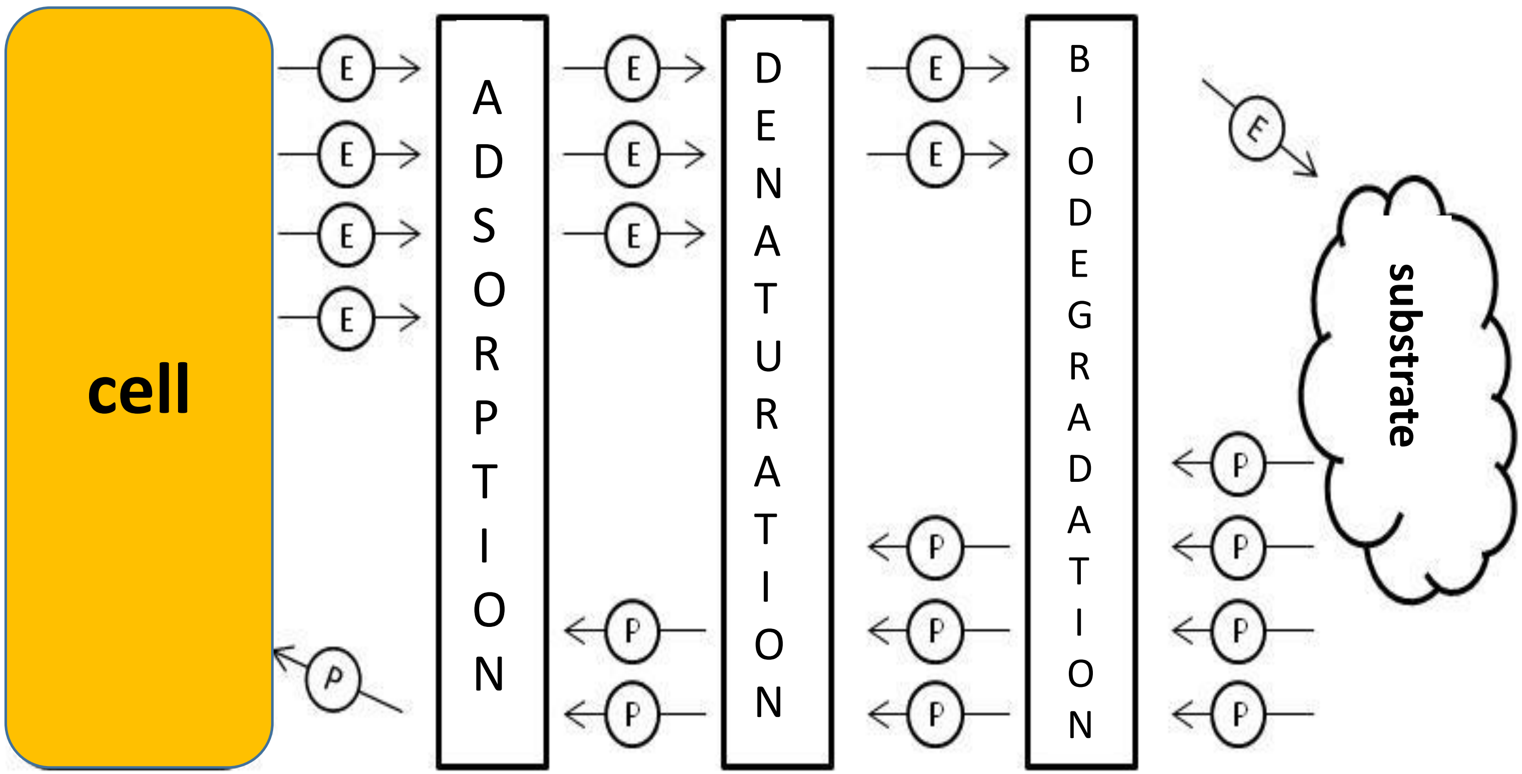
the most important points:

- microbes are homeostatic – they need to get nutrients in a distinct ratio
- if resource nutrient is in excess, microbes release it into the soil and nutrient mineralization prevails immobilization
- if resource nutrient is limiting, microbial growth is driven by the deficient nutrient and there is hardly any nutrient mineralization in the soil

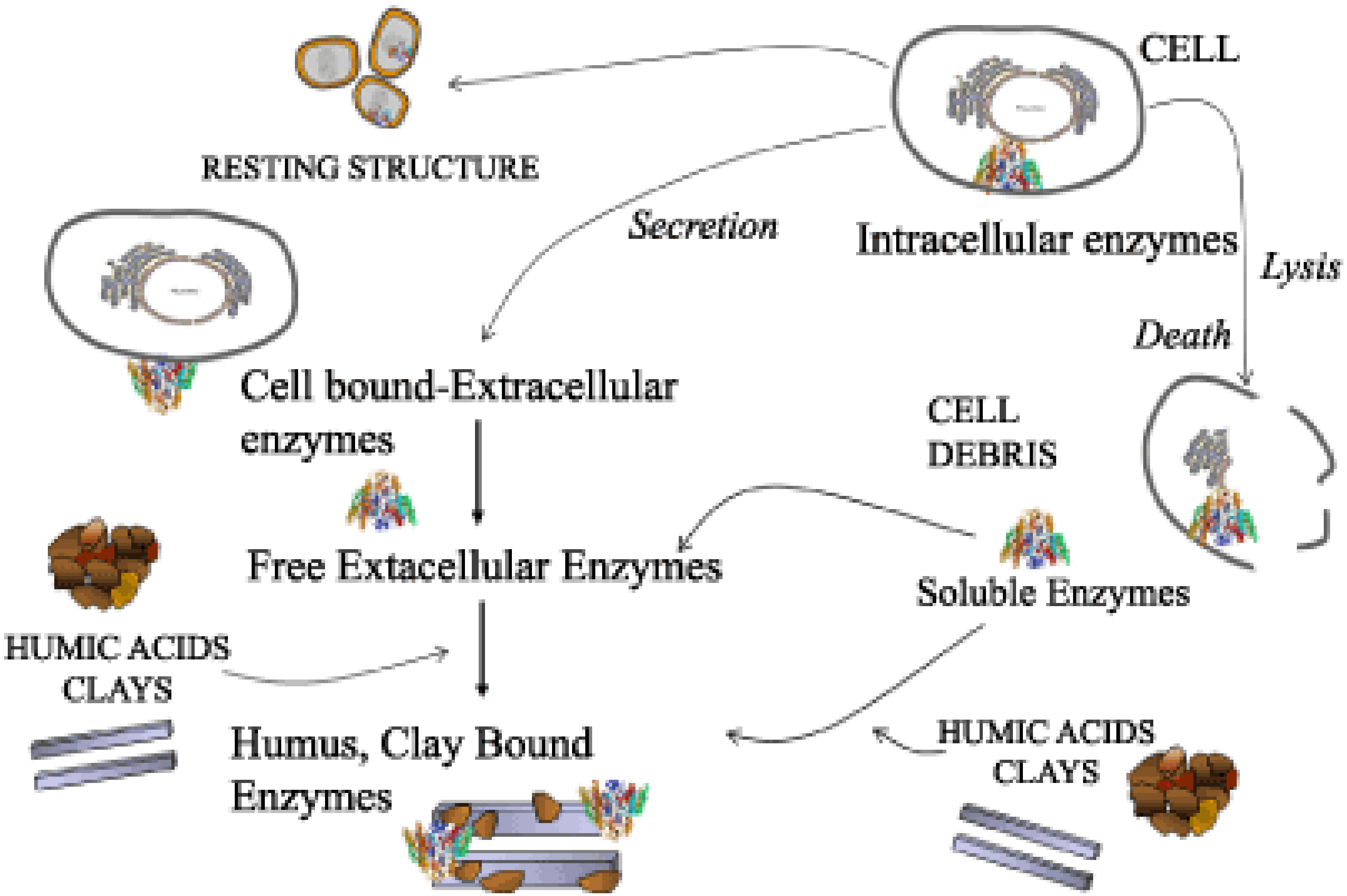
Enzymes

remember: microbes are osmotrophs and soil organic matter is very complex

Microbes must release enzymes from cell to periplasm and into the soil



Origin of enzymes in the soil



http://www.esciencecentral.org/ebooks/enzymes/soil-enzymes.php

Soil enzymatic activity and microbial growth can be to a certain extent disconnected

the most important points:

- vast majority of soil enzymes are of microbial origin
- Soil enzymatic activity and microbial growth can be to a certain extent disconnected

Main factors affecting microbial processes

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- Moisture

    - microbes need water to survive

- Oxygen & redox potential

    - microbes are both, the aerobic & anaerobic

- Temperature

    - ability to adapt
    - activity increases with increasing temperature, in general

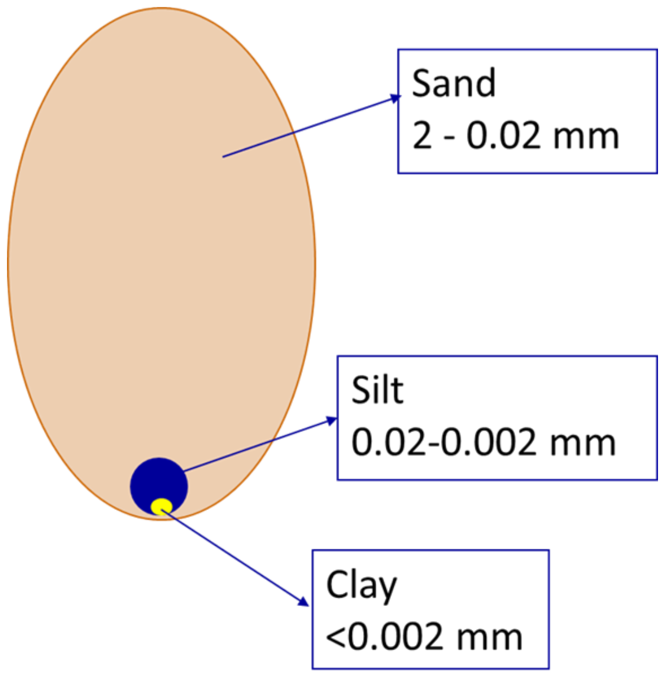
- Soil pH

    - sensitivity depends on type of microbe

- Organic matter

    -soil microbes are mostly heterotrophs (chemoorganotrophs)

water retention and availability depends on
soil texture and structure

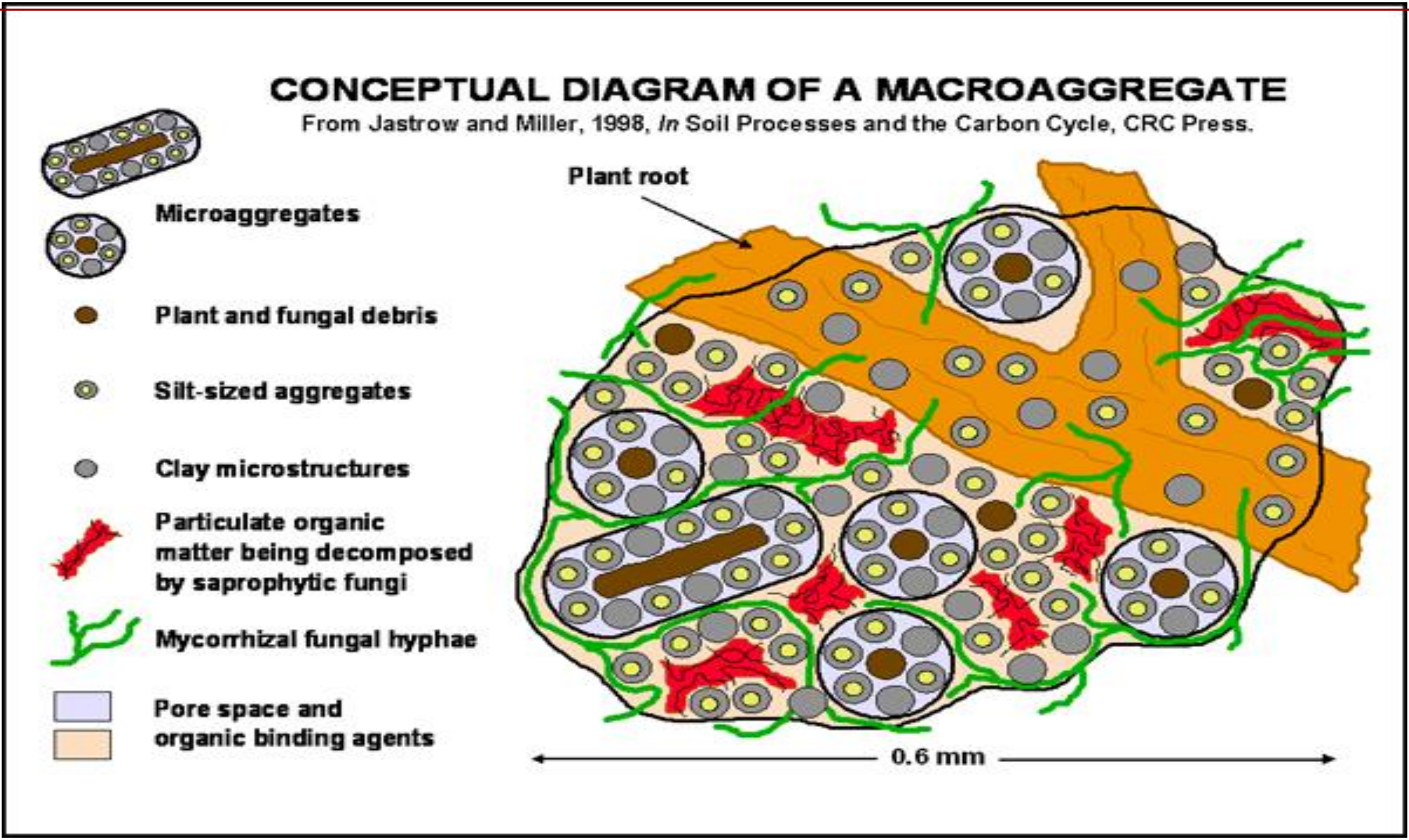


The soil consists of three size classes of mineral particles

But soil also consists of organic matter which together with soil mineral particles makes soil structure

Soil structure

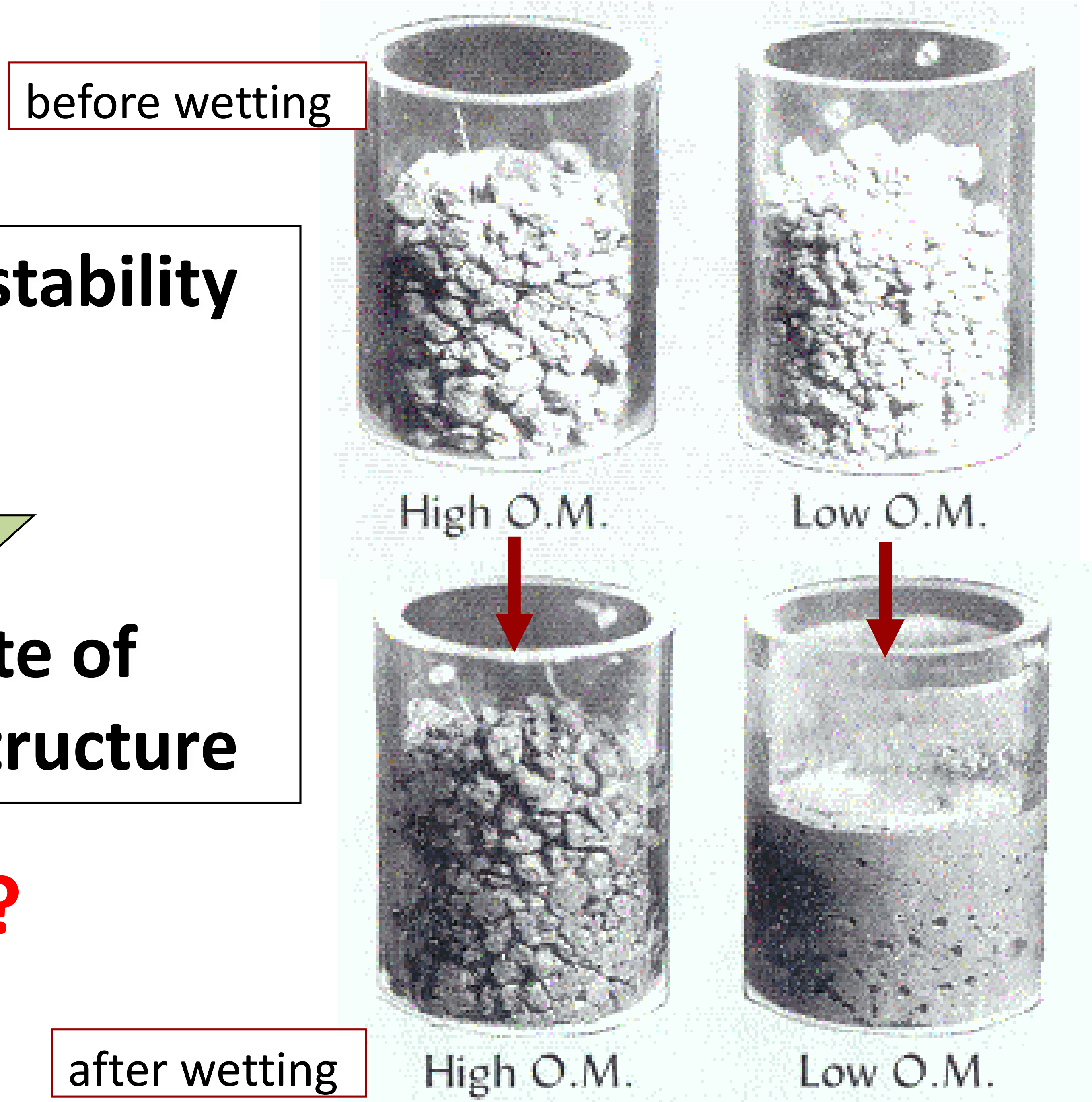
The arrangement of mineral particles and organic material into clumps = **aggregates** *[either macro- (> 0.25 mm) or micro- (< 0.25 mm)]*



Aggregate stability

pre-requisite of good soil structure

??Why??



Modified from Brady, N. C., & Weil, R. R. (2002). *The Nature and Properties of Soils (13th Ed.). Upper Saddle River, NJ: Prentice-Hall, Inc.*

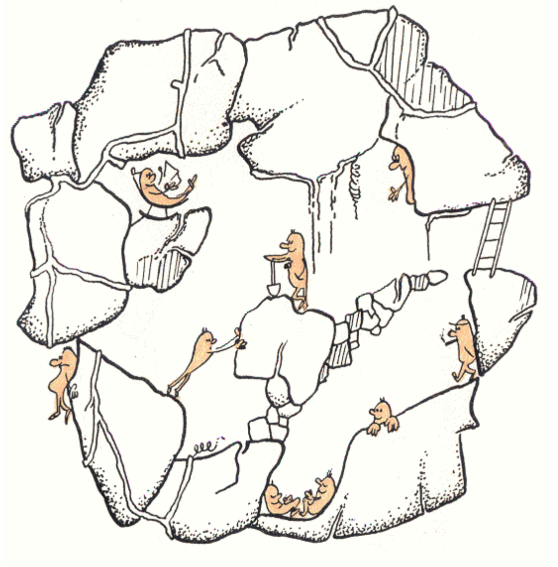
Aggregate stability:

improves

- porosity
- soil aeration
- moisture (water holding capacity)
- ability of soil to retain nutrients

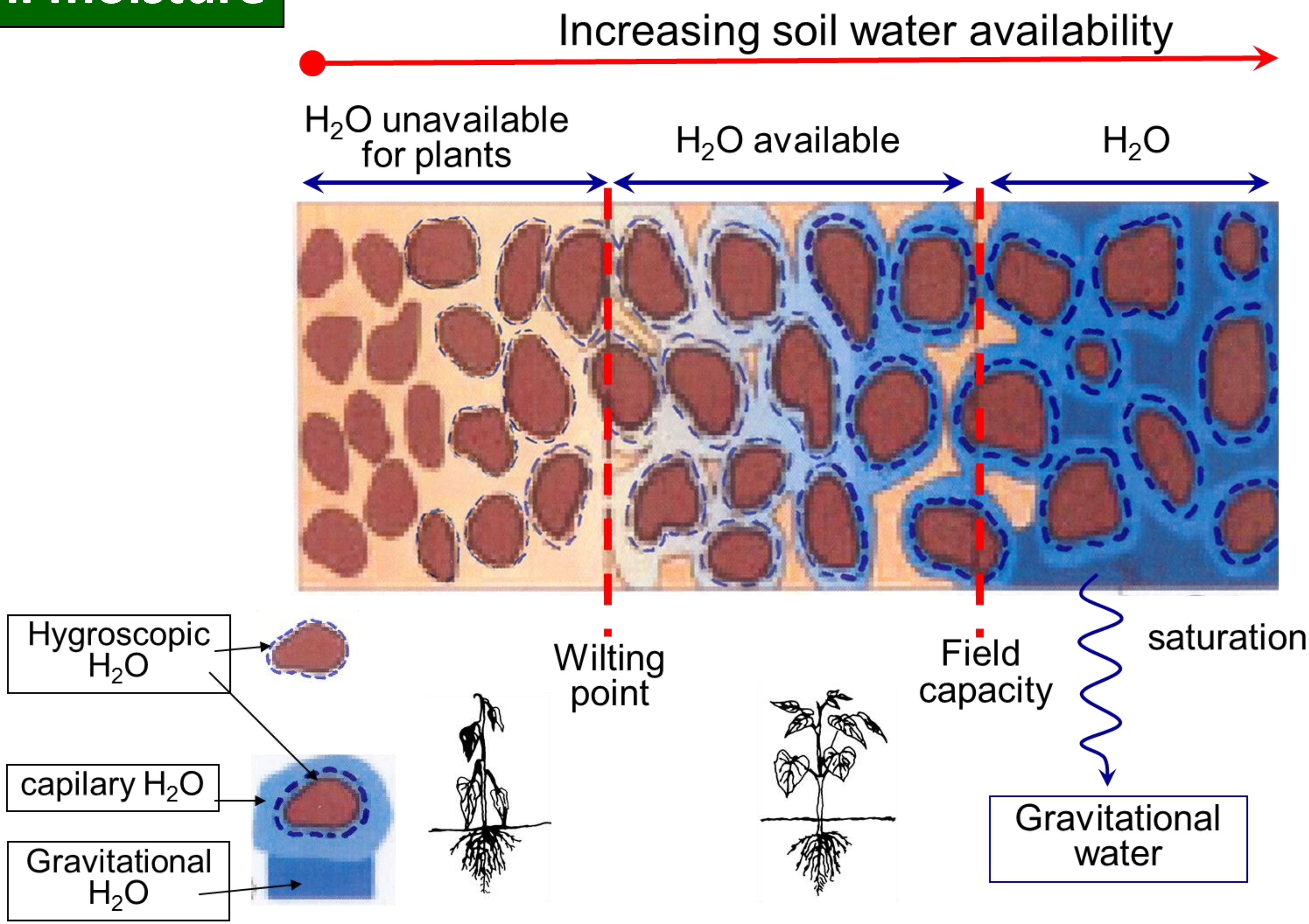
creates suitable environment for soil biota & plant roots

essential for life in the soil



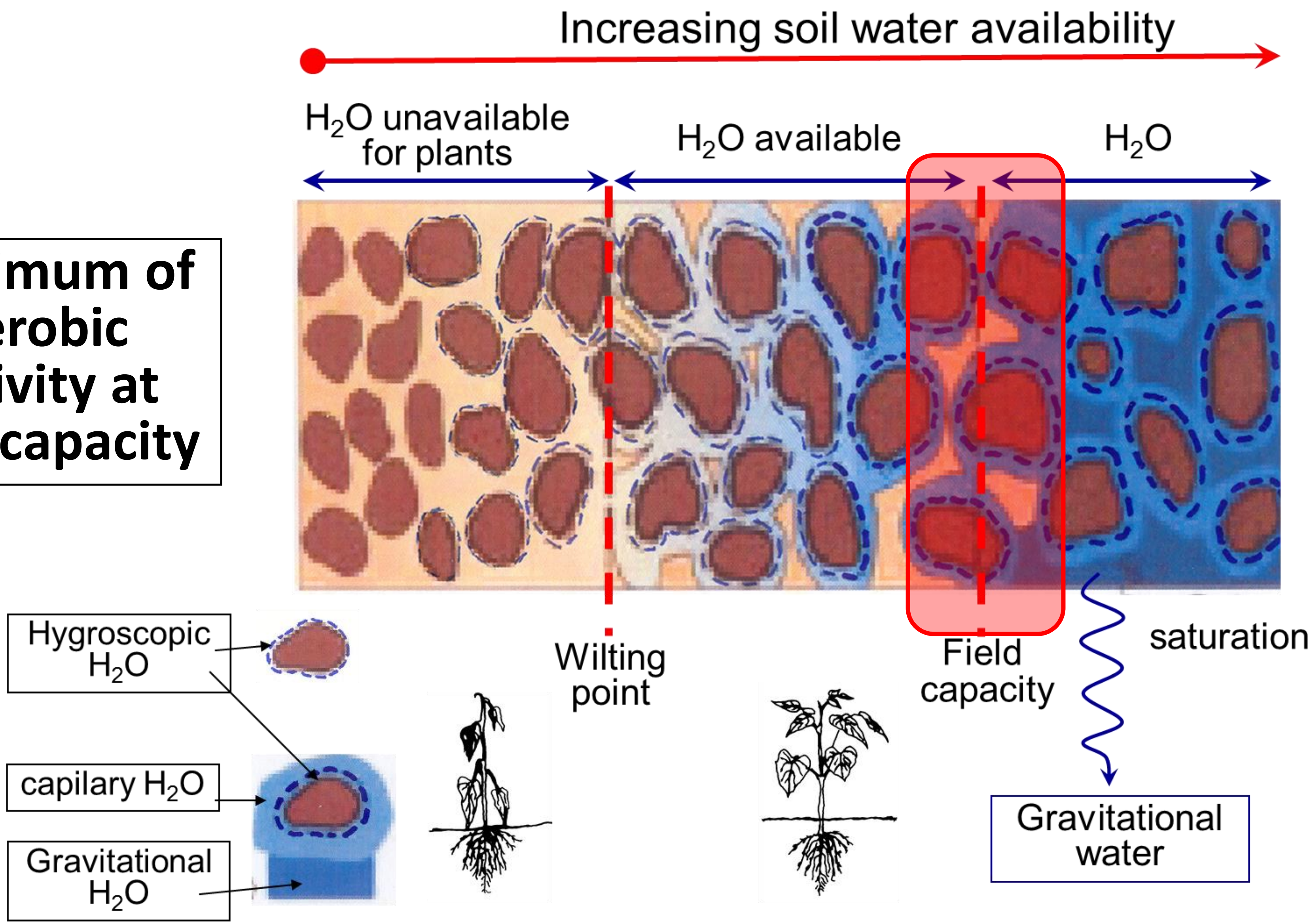
Josef Chalupský

Soil moisture



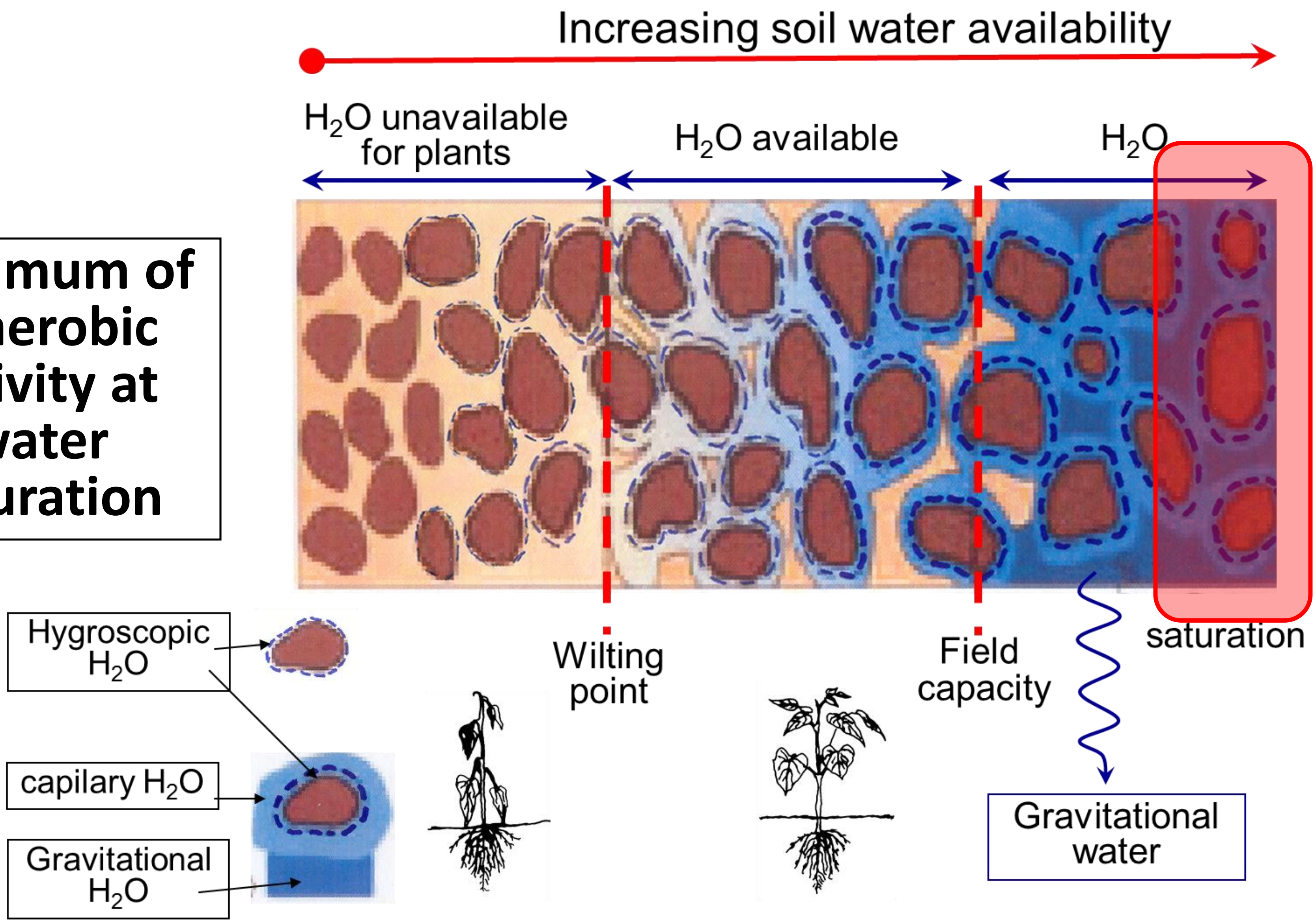
?? Maximum of aerobic activity??

Maximum of aerobic activity at field capacity



?? Maximum of anaerobic activity??

Maximum of anaerobic activity at water saturation



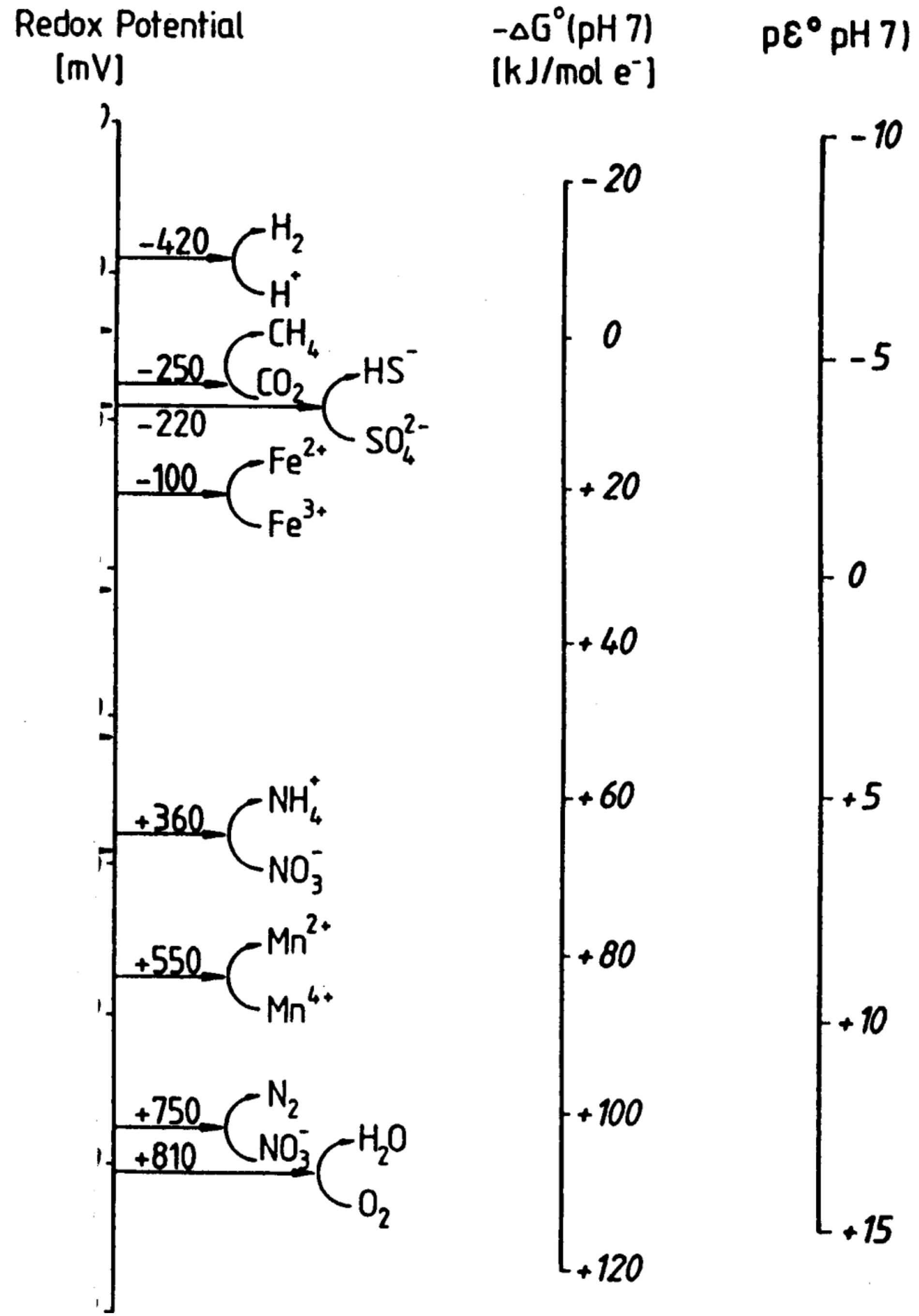
But it depends on OM content and availability much more than aerobic processes

Organic matter availability enhances microbial activity which determines in flooded soils

Redox potential

see previous lectures

message of this picture?



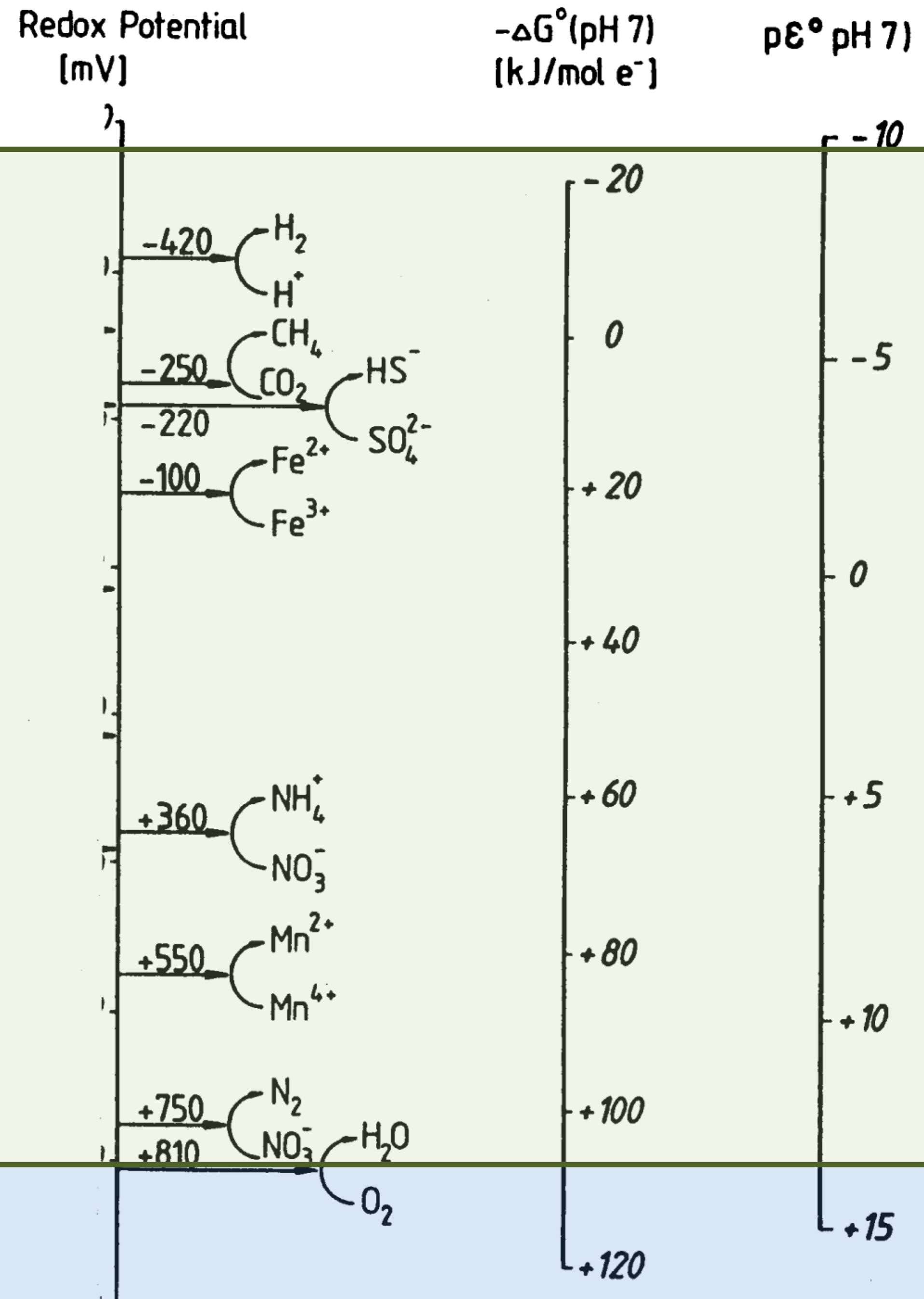
Redox potential

anaerobic conditions & anaerobic food chain

methanogenesis & sulphur reduction

fermentation

anaerobic respiration

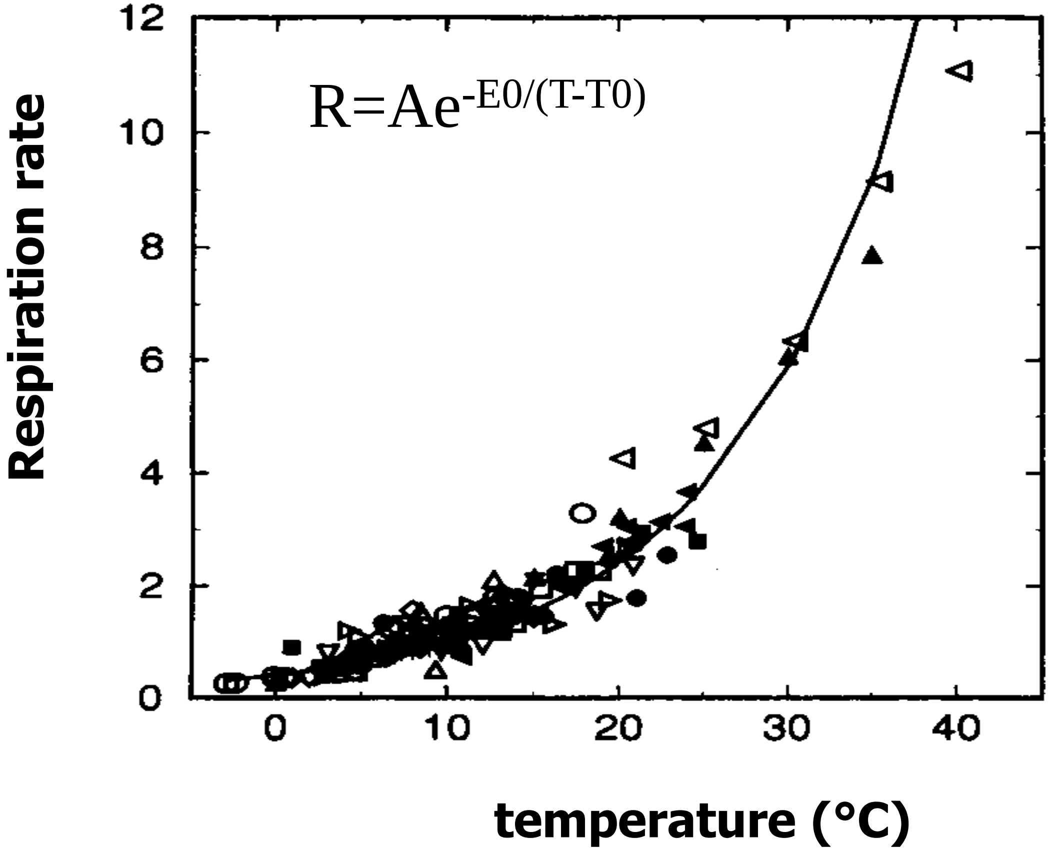


aerobic conditions

aerobic respiration

Soil temperature

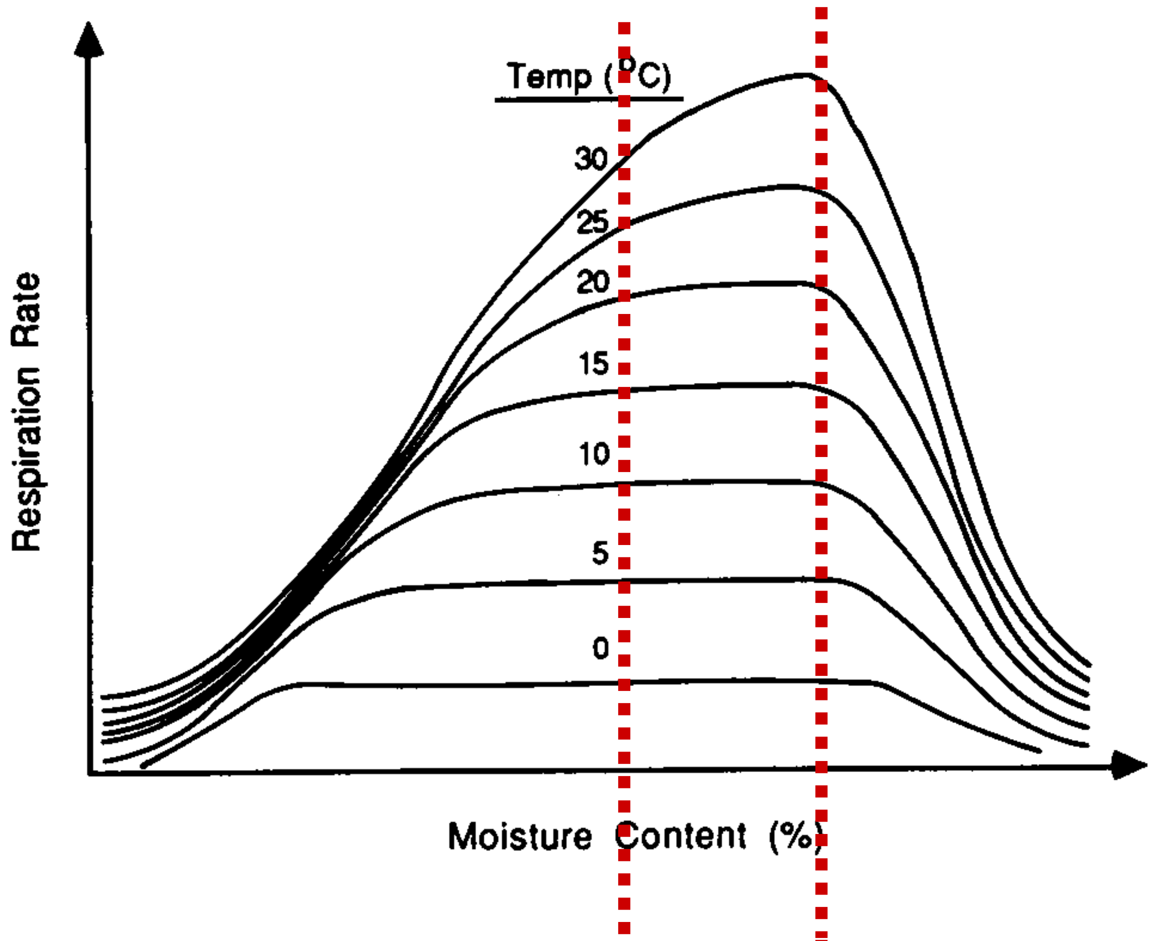
The increase of respiration with temperature – exponential



Temperature dependency – Arrhenius type equation

Lloyd J. & Taylor J.A. 1994, Funct. Ecol. 8, 315-323

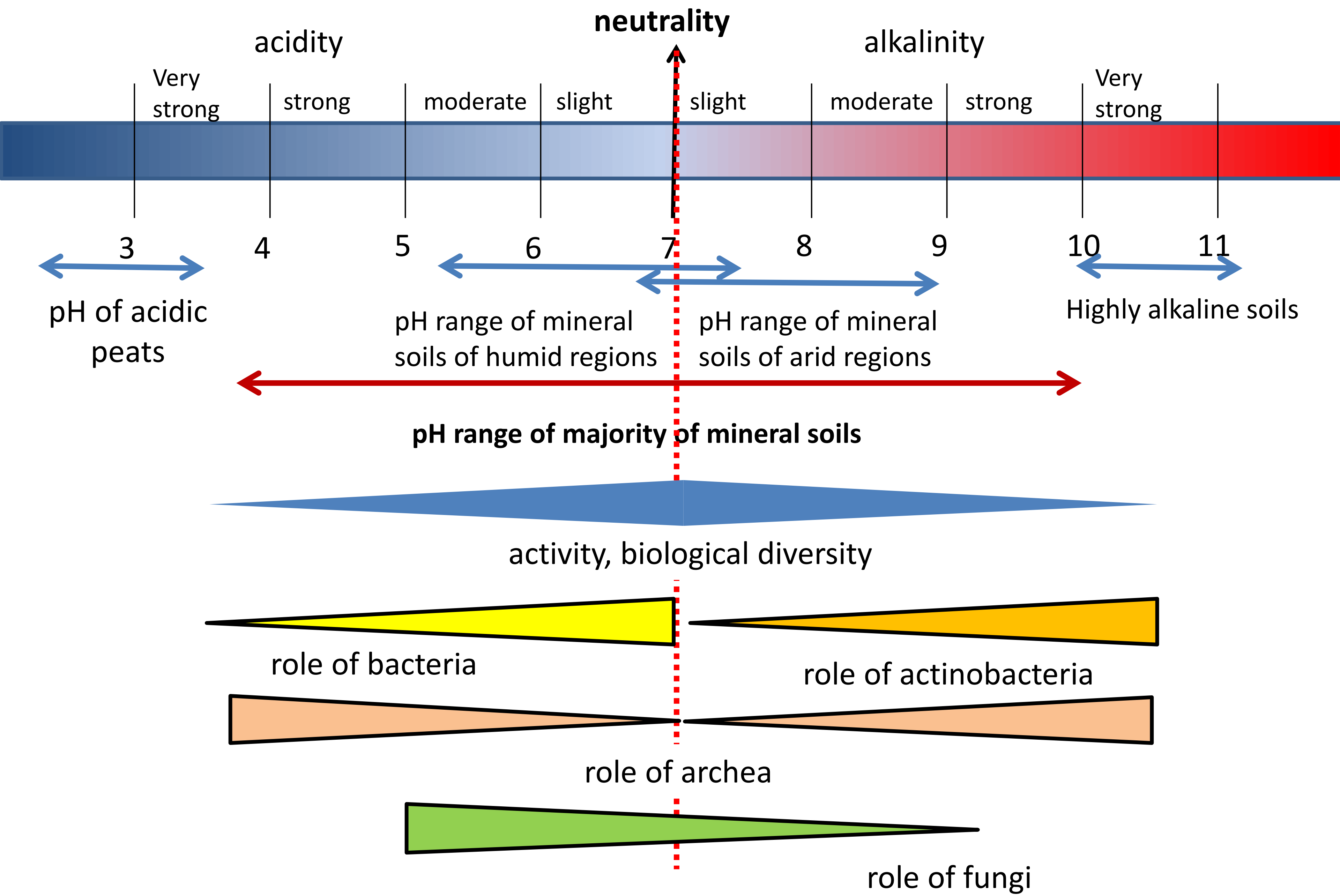
Confounding effect of moisture & temperature



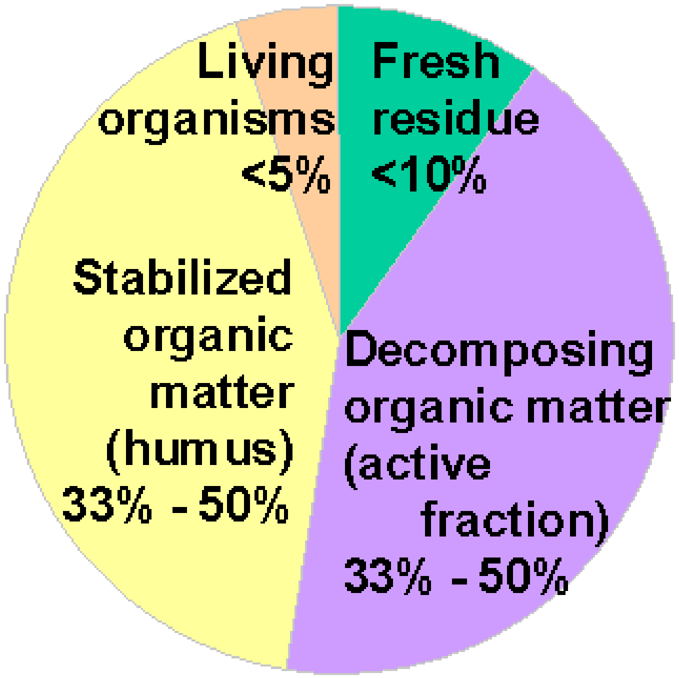
Largest temperature response is at optimum moisture (field capacity)

Paul, E. A., & Clark, F. E. (1989). *Soil Microbiology and Biochemistry. Academic Press, San Diego*, 81-84.

soil pH - range and classification



Substrate and nutrient availability

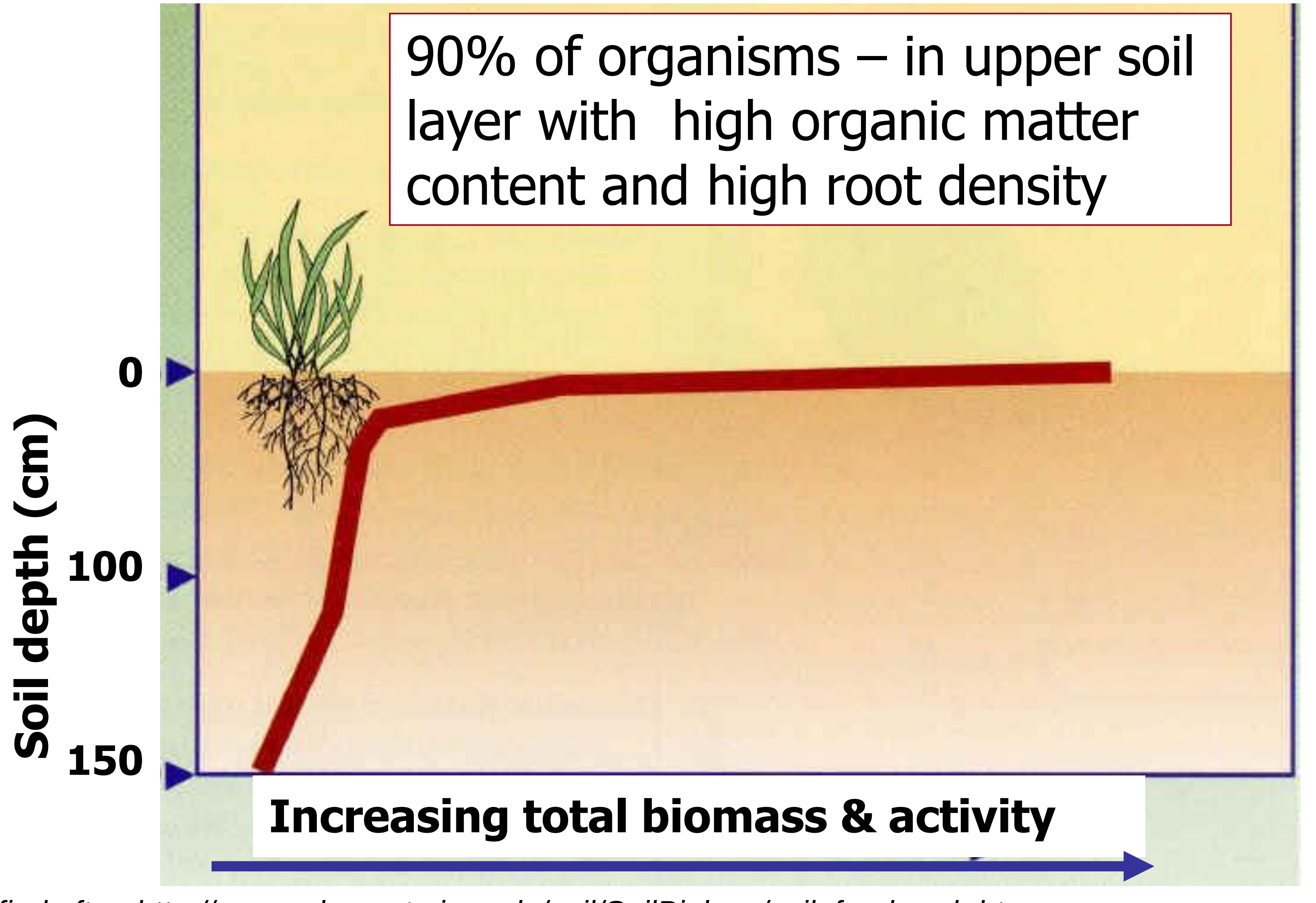


http://extension.illinois.edu/soil/SoilBiology/soil_food_web.htm

Proportion of organic fractions determines:

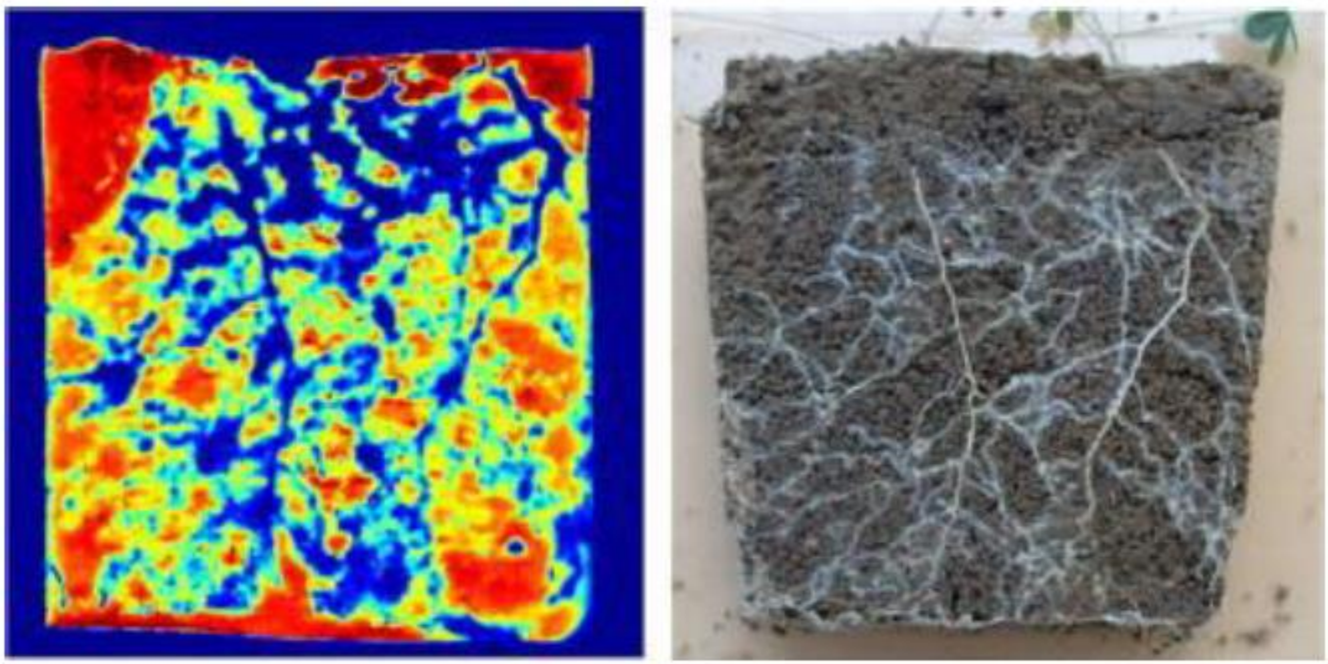
- **resource stoichiometry (C/N, C/P, N/P ratios)**
- **C and nutrient availability**
- **decomposition rate**
- **composition of microbial community**
- **Organic matter and soil stability**

Soil microbes live mainly in the upper part of soil profile: their biomass and activity decrease with soil depth



Modified after: http://www.urbanext.uiuc.edu/soil/SoilBiology/soil_food_web.htm

Spatial variability of substrate availability and thus microbial and enzyme activities in soil is enormous



Take home message: never ever memorize only. Think of principles, causality and background of the processes

Microbial processes in soil II

Why we are so interested in soil microbial processes ?

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Lecture II:

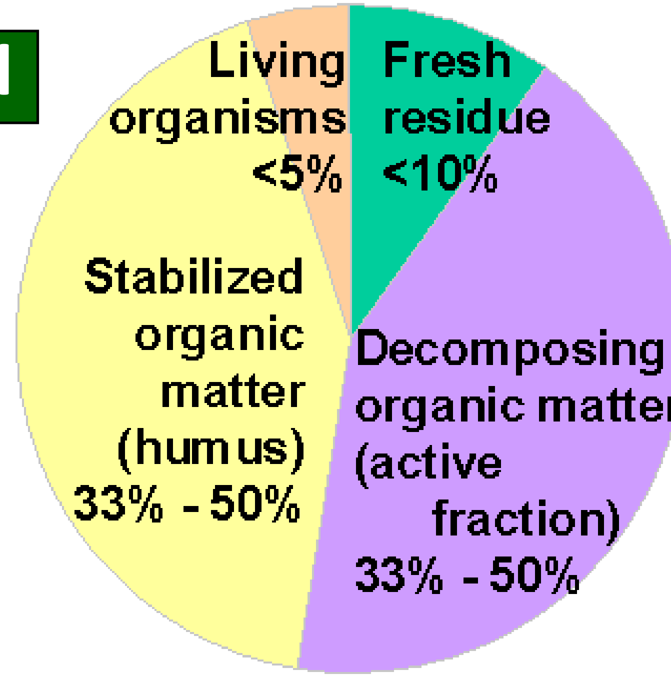
- **C transformations**
- **N transformations**
- **P transformations**

Carbon (organic matter) transformations

C is a building block of biomass and donor of electrons in source of energy

BUT during organic matter transformation also nutrients are released

Organic matter fractions in the soil



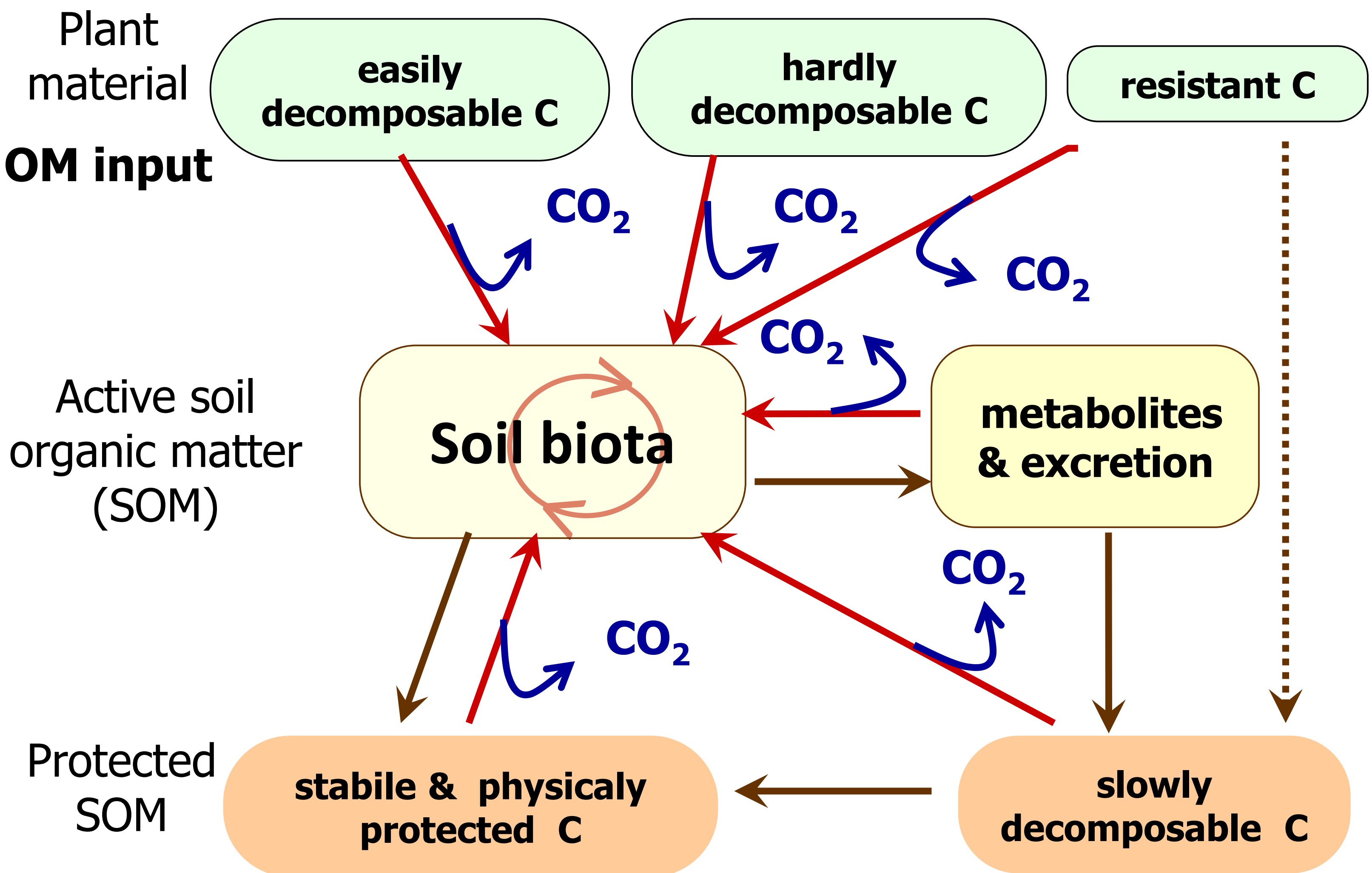
http://extension.illinois.edu/soil/SoilBiology/soil_food_web.htm

Proportion and quality of organic fractions determines:

- **resource stoichiometry (C/N, C/P, N/P ratios)**
- **C and nutrient availability**
- **decomposition rate**
- **composition of microbial community**
- **Organic matter and soil stability**

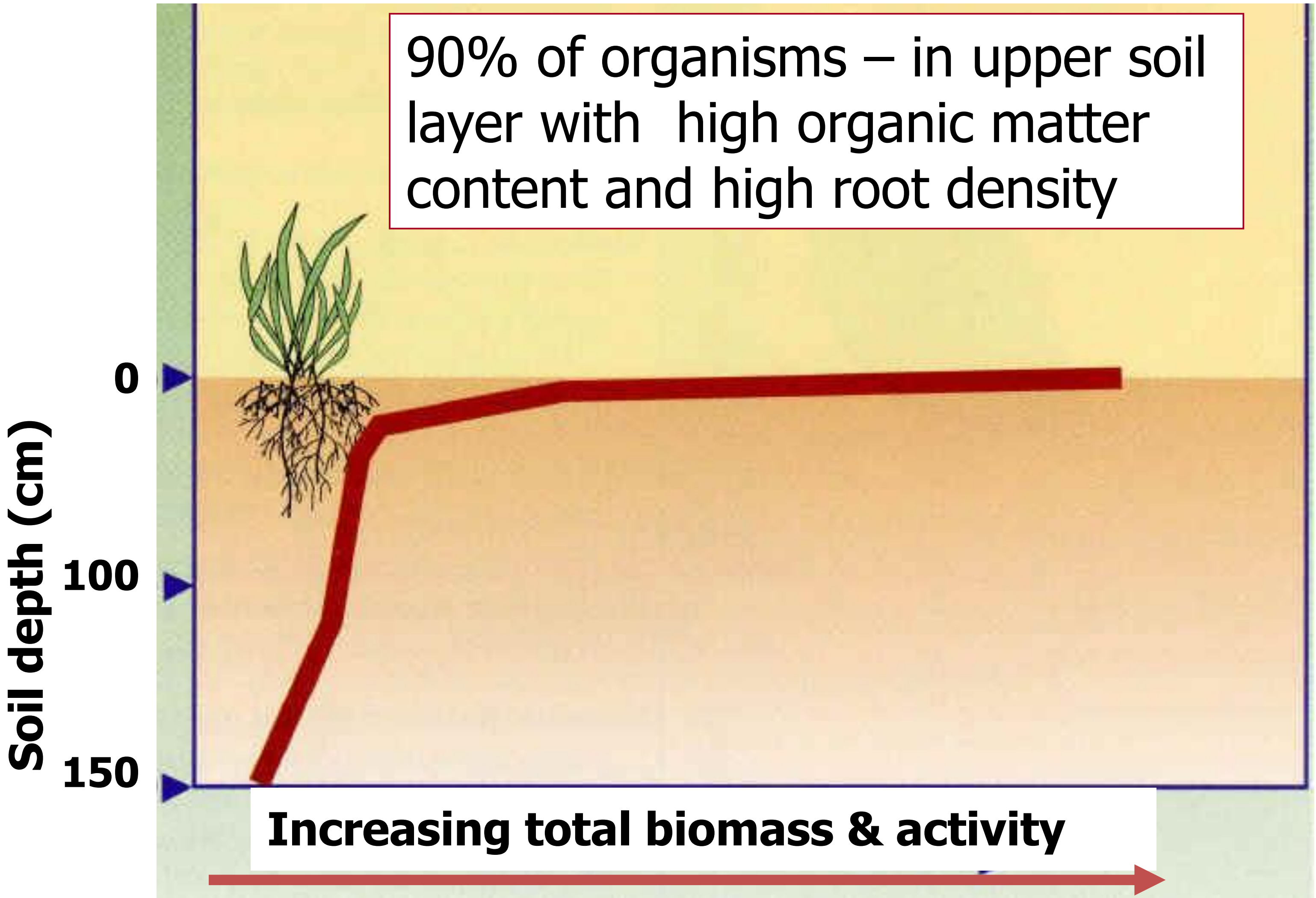
? What is the main source of organic matter to the soil?

Organic matter (OM) sources



Soil organic matter (SOM) –plant material transformed by activity of soil biota (mainly microorganisms)

Soil microbes live mainly in the upper part of soil profile: their biomass and activity decrease with soil depth



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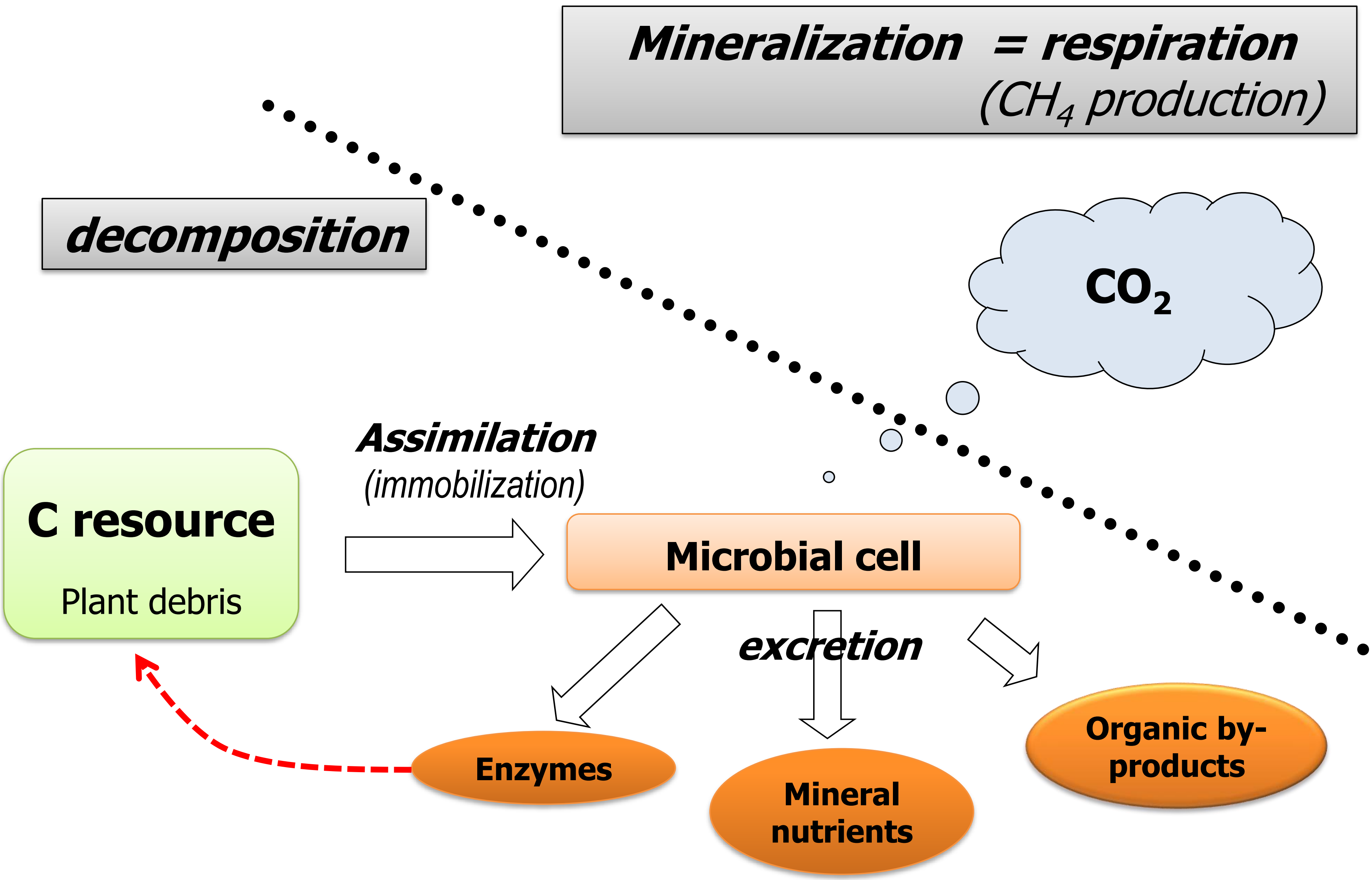
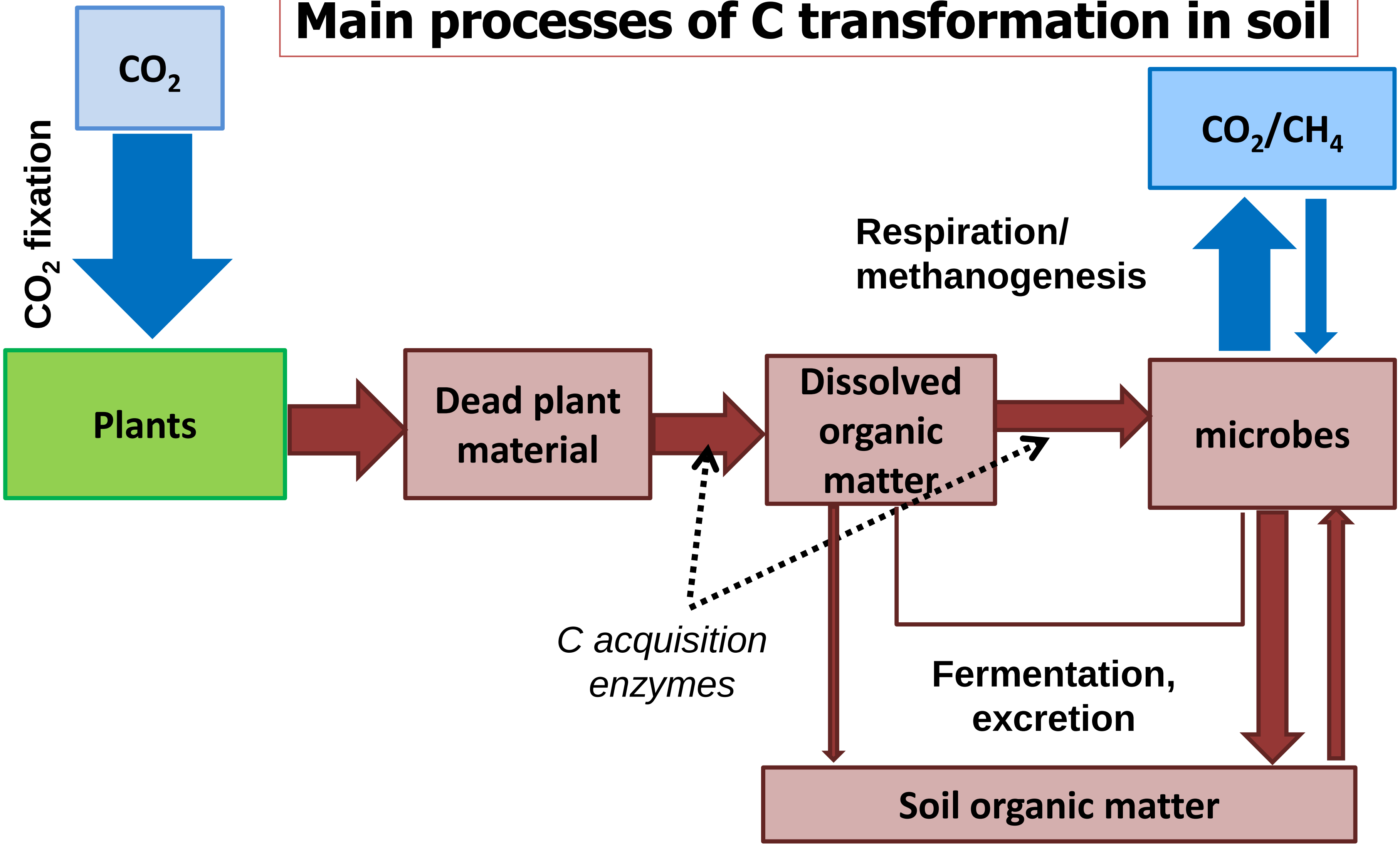


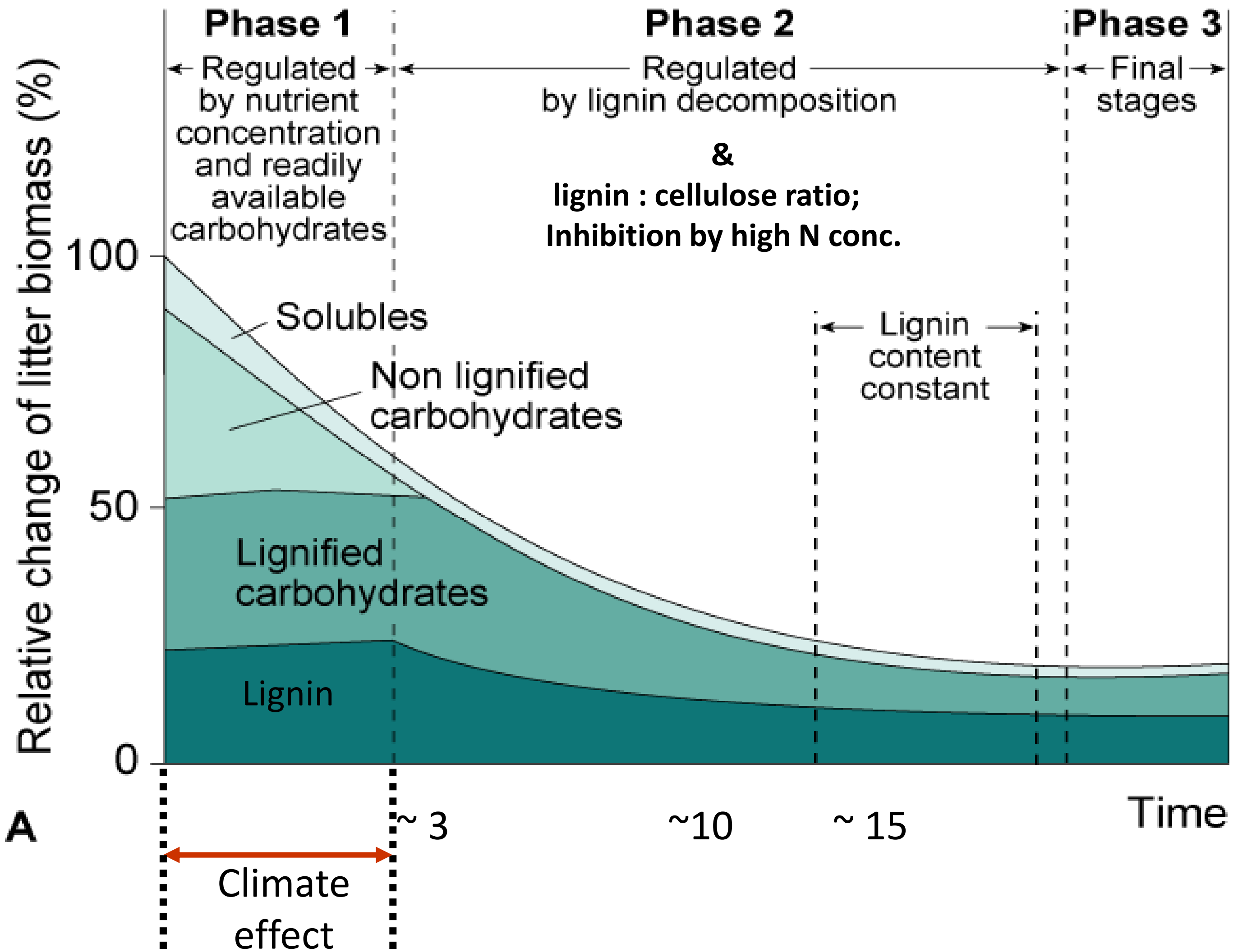
Mineralization = respiration
(CH_4 production)
decomposition
CO_2
Assimilation
(immobilization)
C resource
Plant debris
Microbial cell
excretion
Enzymes
Mineral nutrients
Organic by-products

Main processes of C transformation in soil



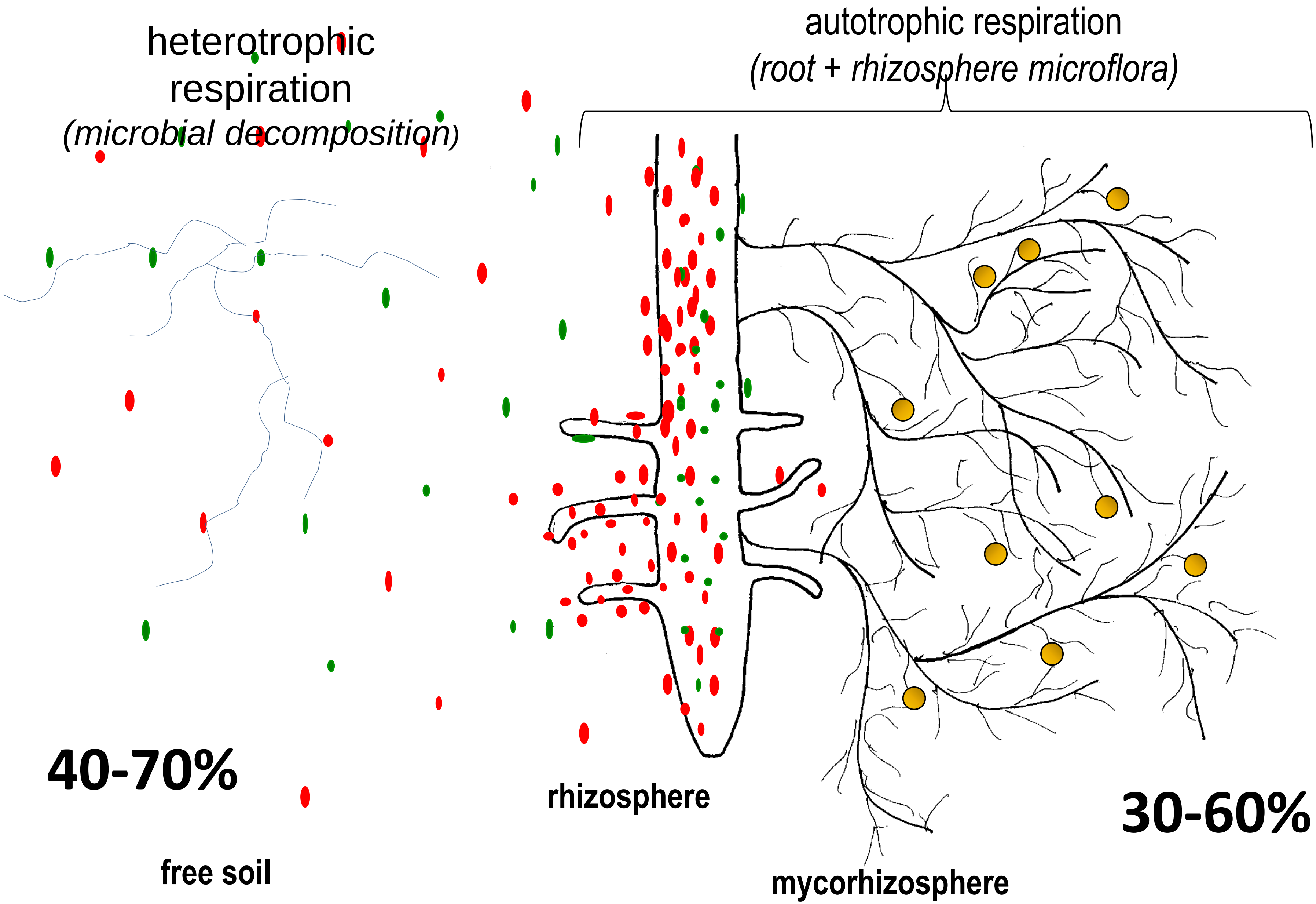
Proportion between C mineralization and C immobilization to microbial biomass and SOM depends on resource to consumer stoichiometry, C availability and environmental conditions

Organic matter decomposition



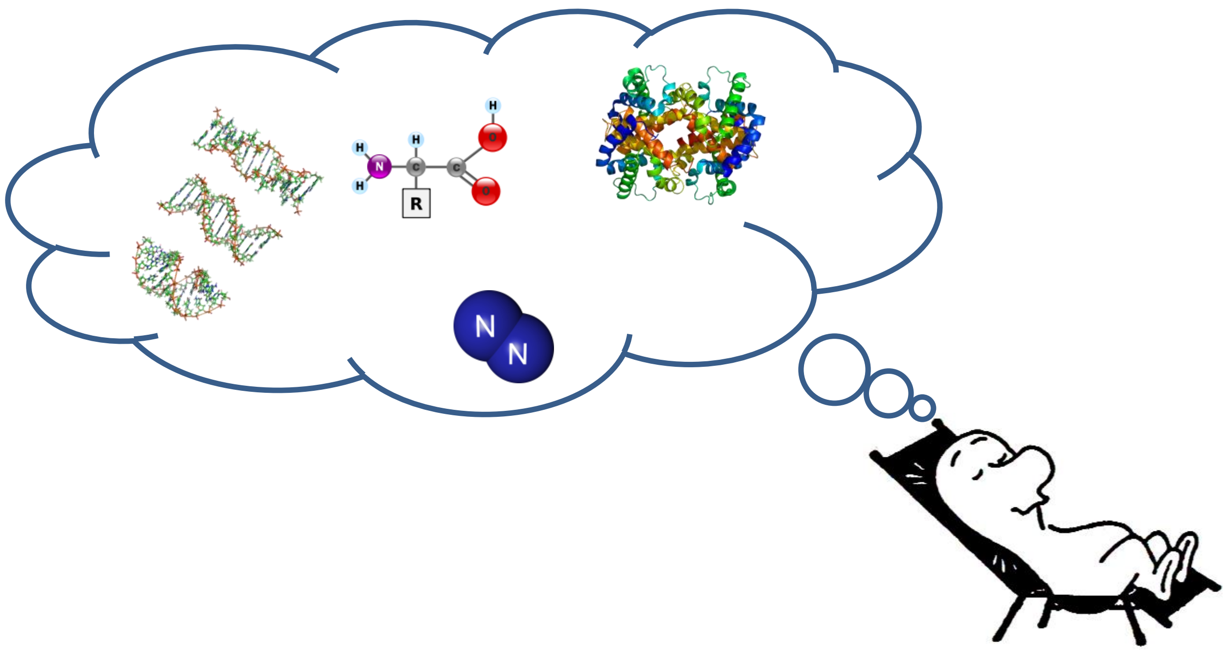
Modified from Berg, B., & Matzner, E. (1997). *Environmental Reviews*, *5*(1), 1-25.

The most common measure of C transformations in soil - total soil respiration

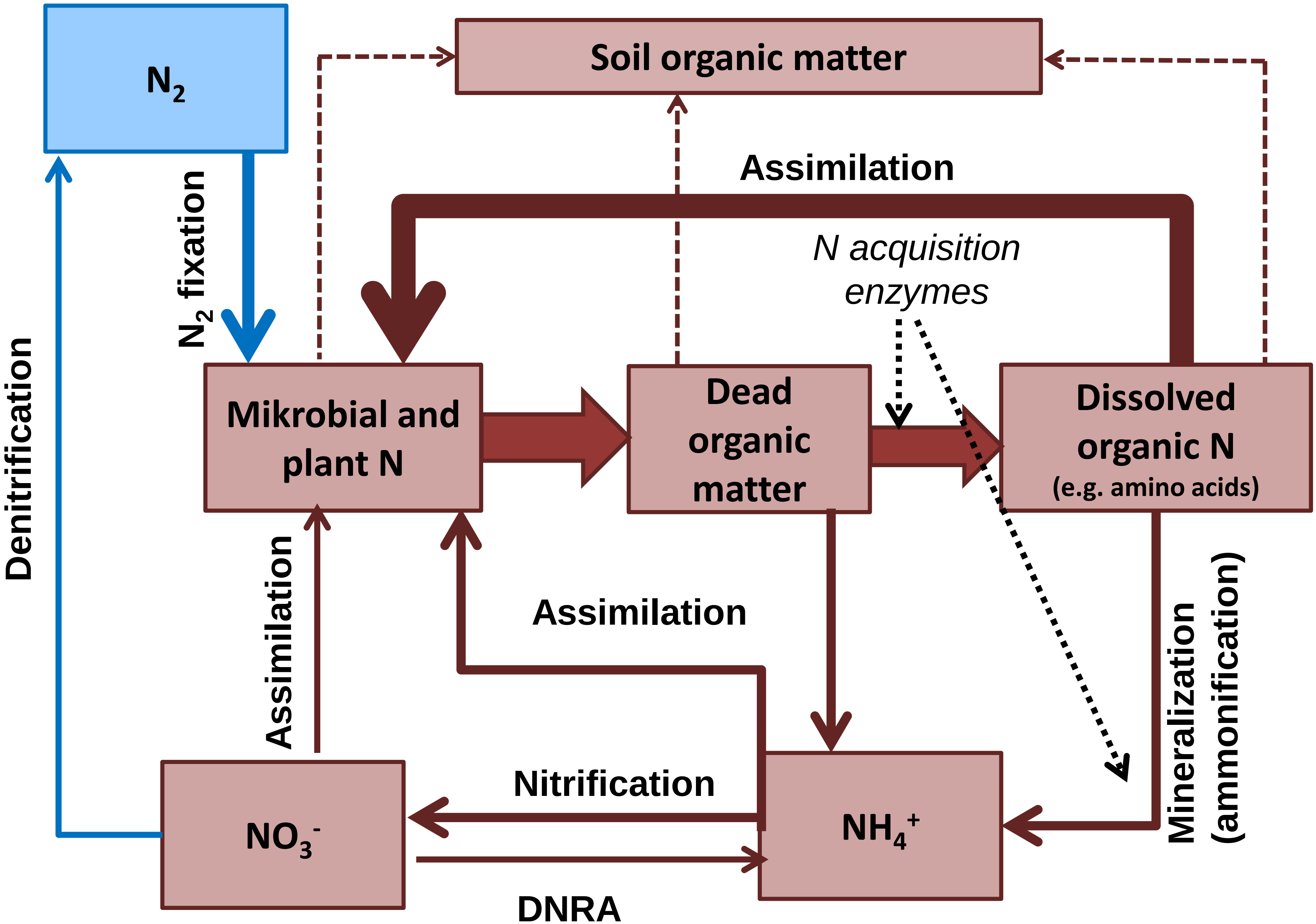


Nitrogen transformations

N is an essential element of biomass and donor and acceptor of electrons in energy metabolism

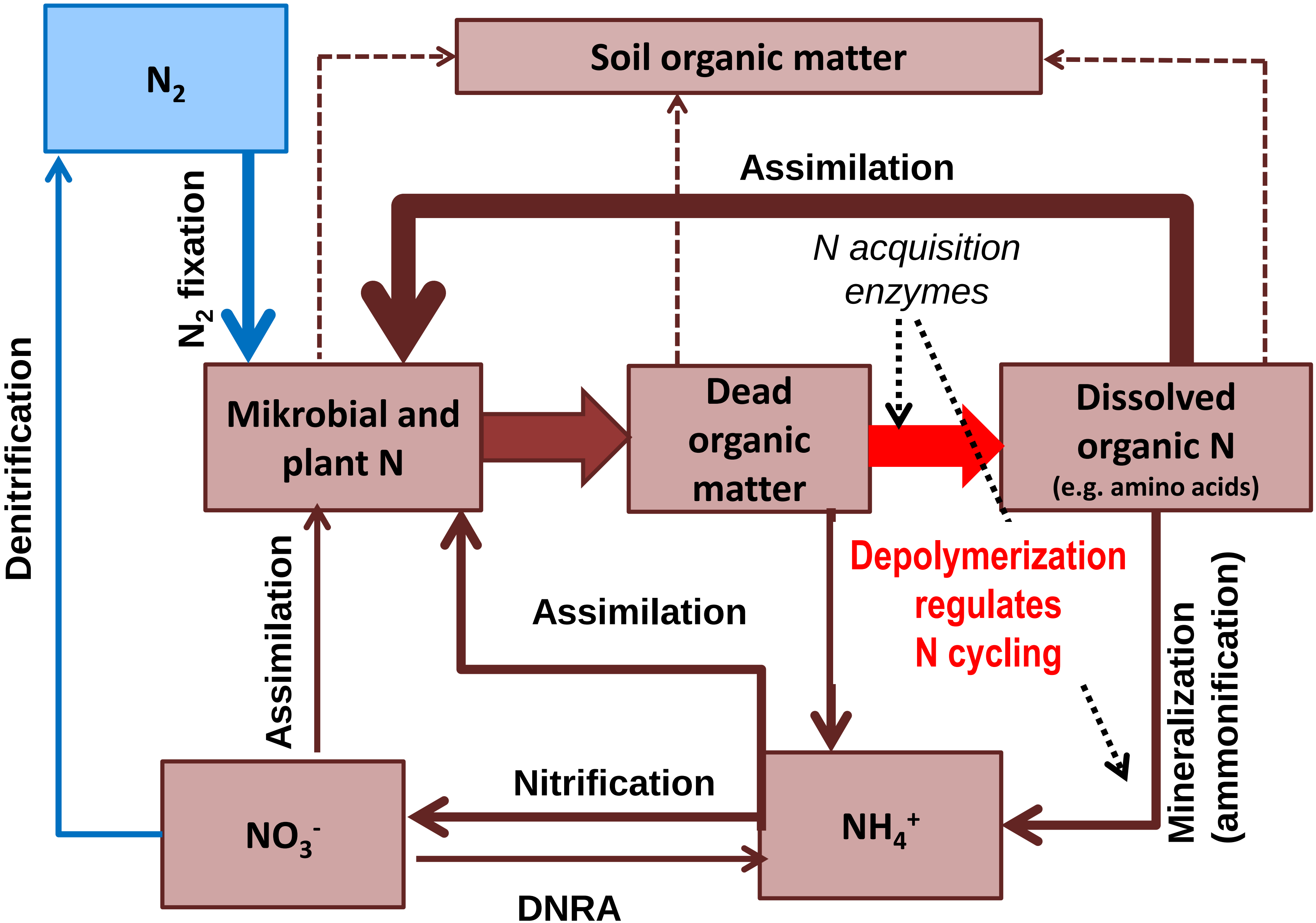


Main processes of N transformation in soil



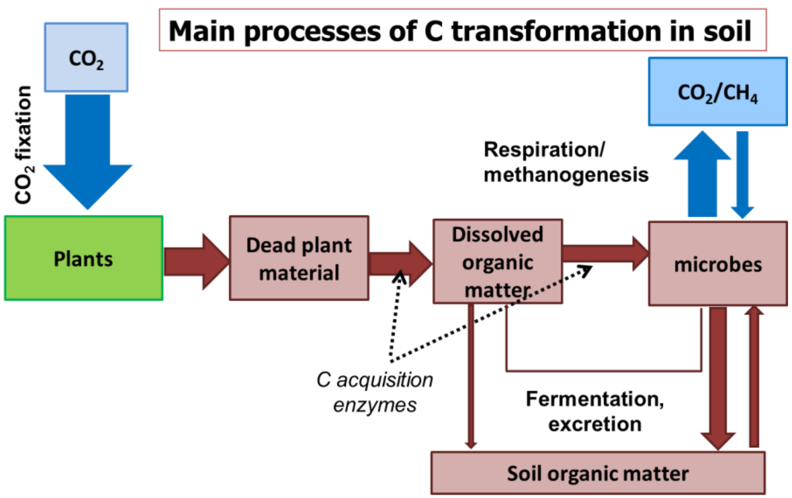
DNRA = dissimilative nitrate reduction

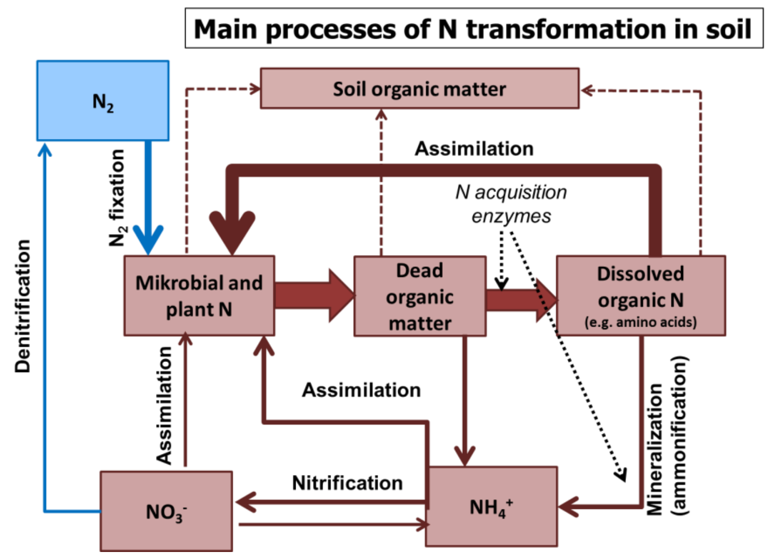
Main processes of N transformation in soil



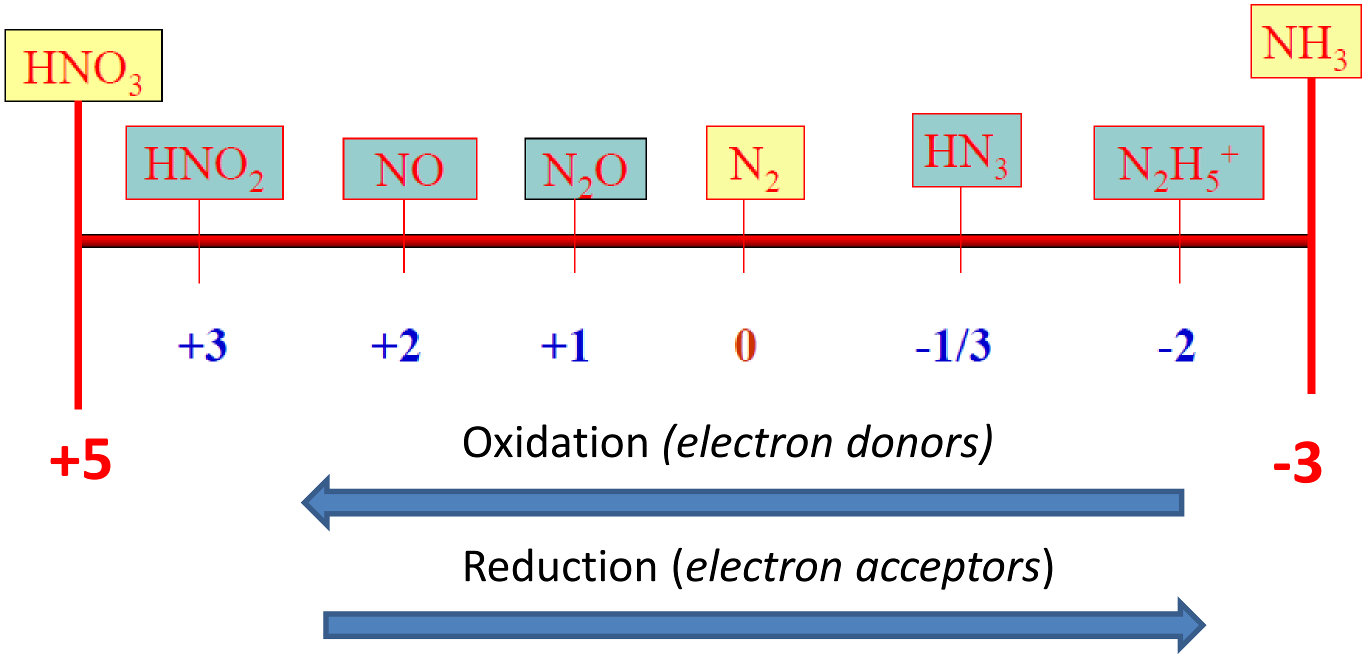
DNRA = dissimilative nitrate reduction

Why are N transformations in soil so complicated?





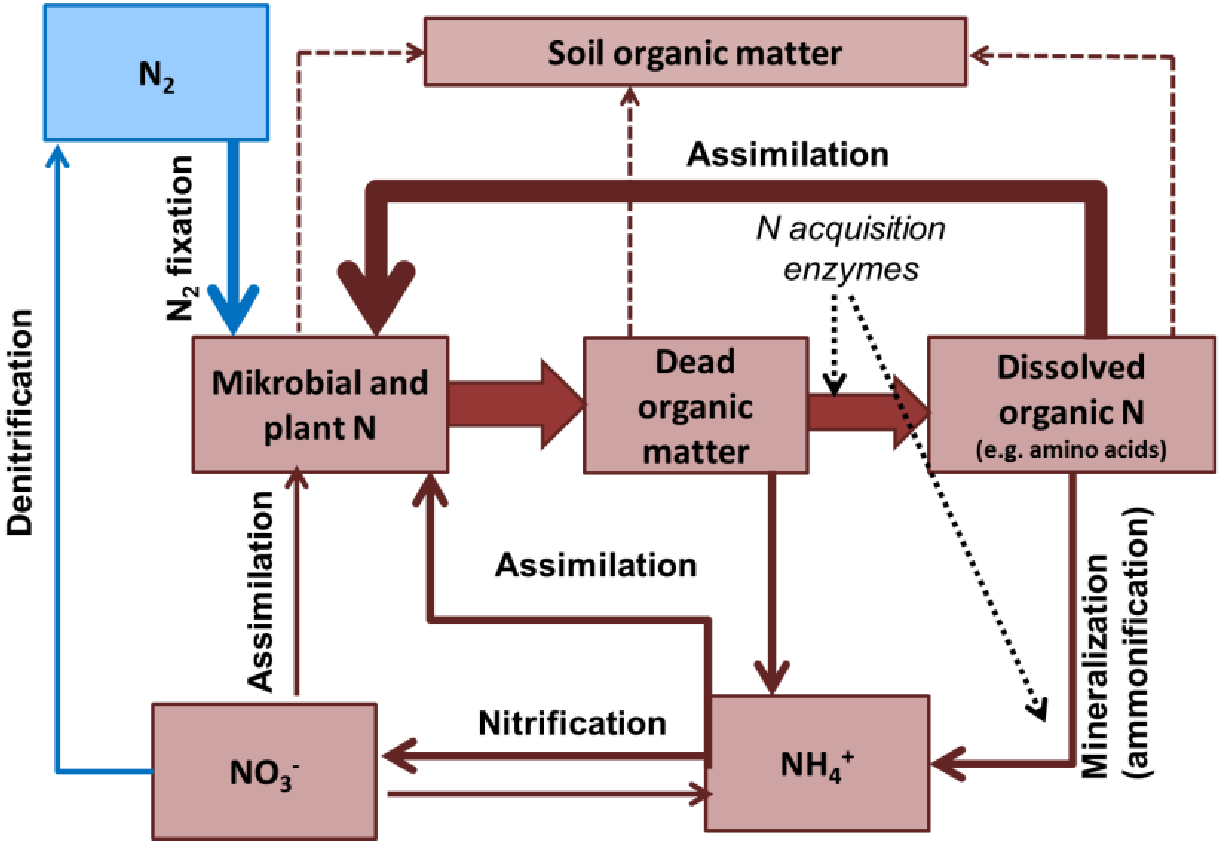
Nitrogen exists in different oxidation states:



- N is a source of nutrient to build biomass — **Biosynthesis**
- N is an electron donor (is oxidized)
- N is an electron acceptor (is reduced)

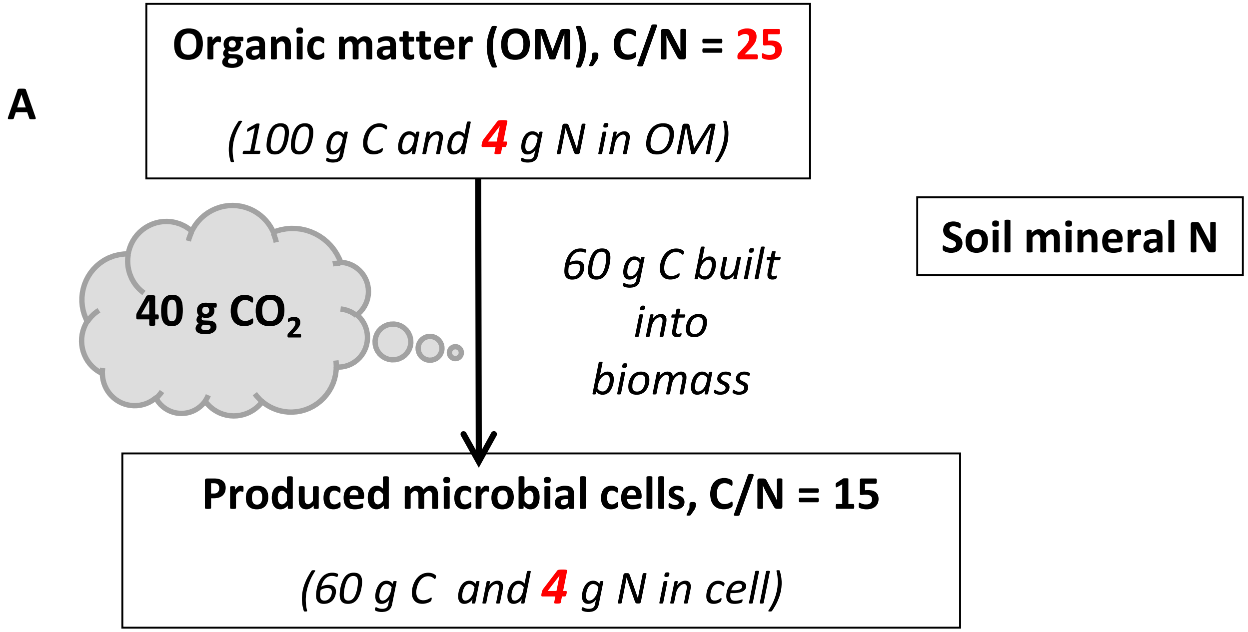
(The last two bullets point to: **Energy metabolism**)

Main processes of N transformation in soil

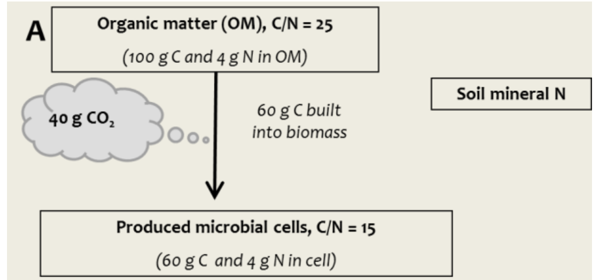


N mineralization and assimilation run in the same time. The equilibrium between them depends on resource to consumer stoichiometry.

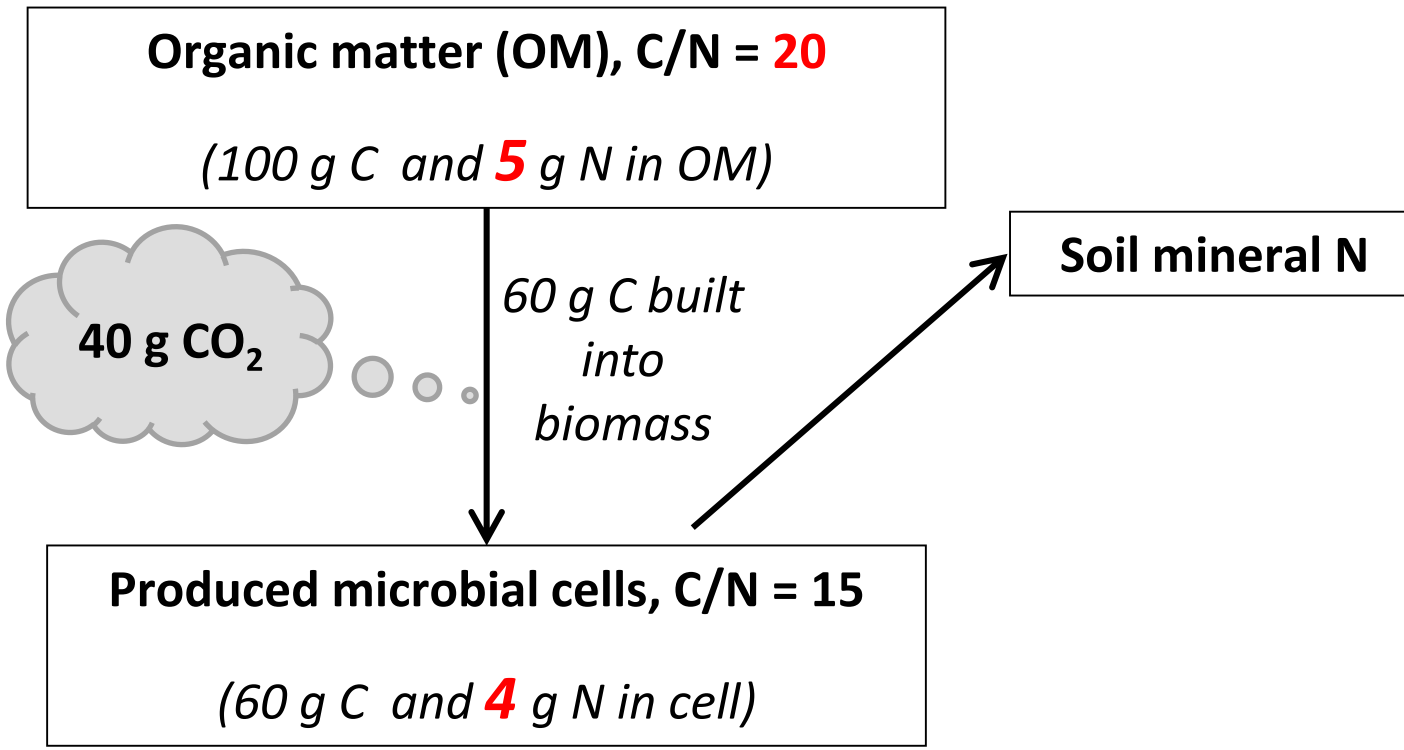
It is generally accepted that N immobilization prevails N mineralization if C/N ratio of SOM is around 25
(but many exceptions in literature)



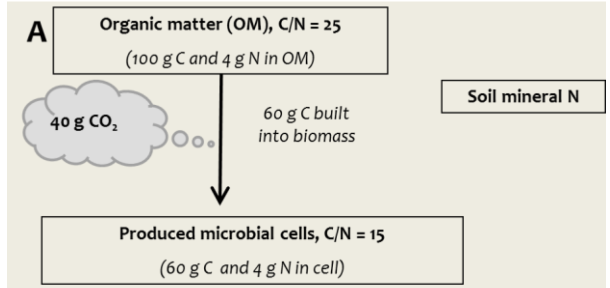
N mineralization and immobilization are in equilibrium

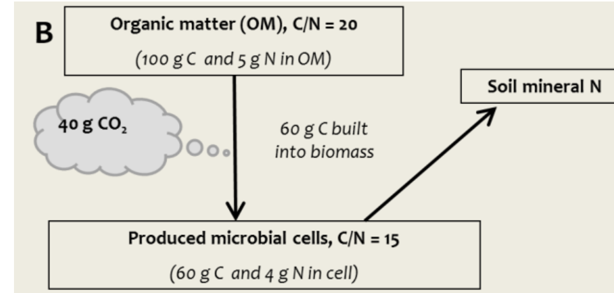


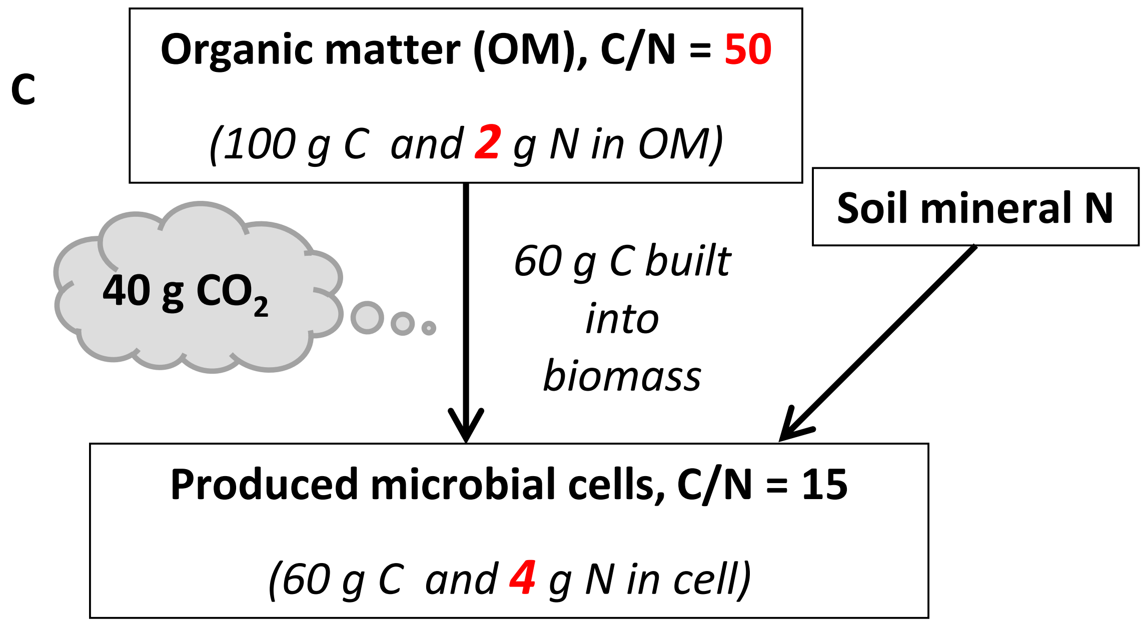
B



N is in excess- N mineralization prevails







N defficiency - N immobilization prevails

N_2 fixation

Molecular nitrogen is reduced and build into biomass

$$N_2 + 8H^+ + 8e^- + 16\,ATP \rightarrow 2\,NH_3 + H_2 + 16\,ADP + 16\,P_i$$

*Enzyme **nitrogenase***
(sensitive to oxygen)

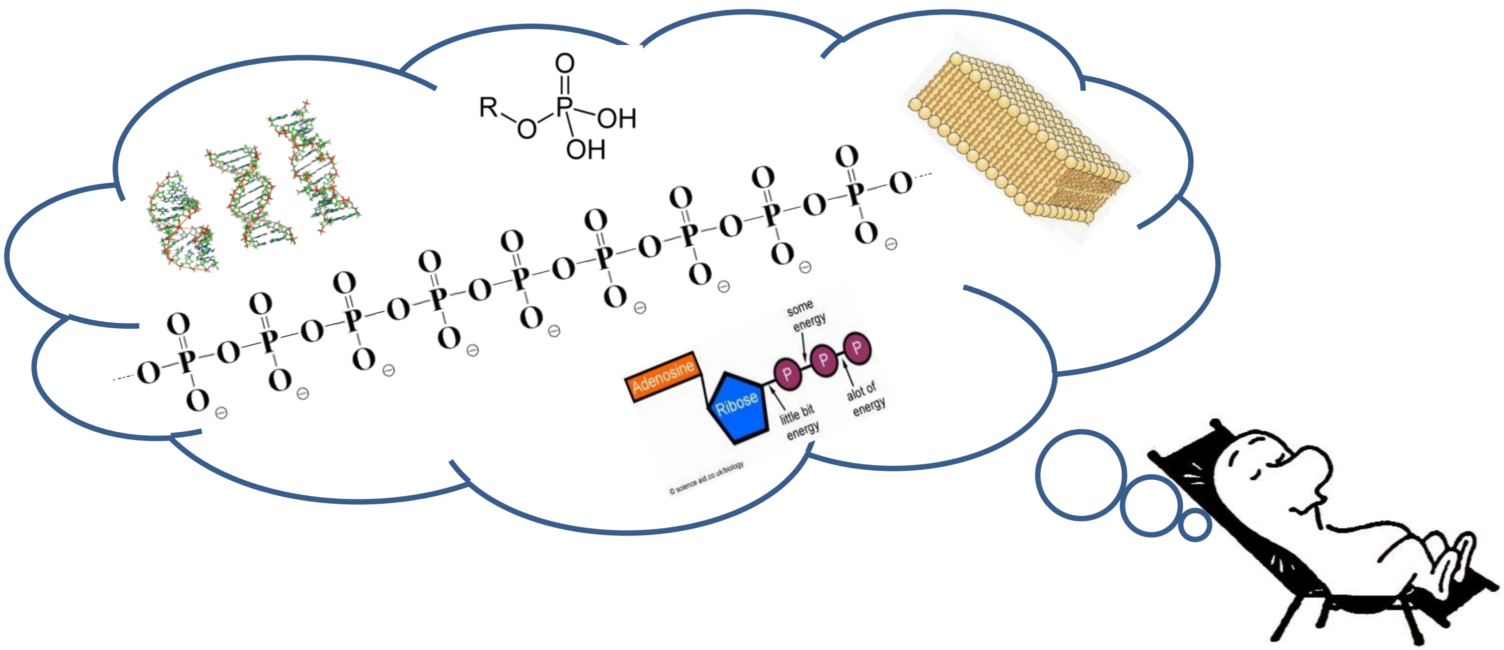
N_2 fixators belong to prokaryota only

N_2 fixation depends on high C & P availability

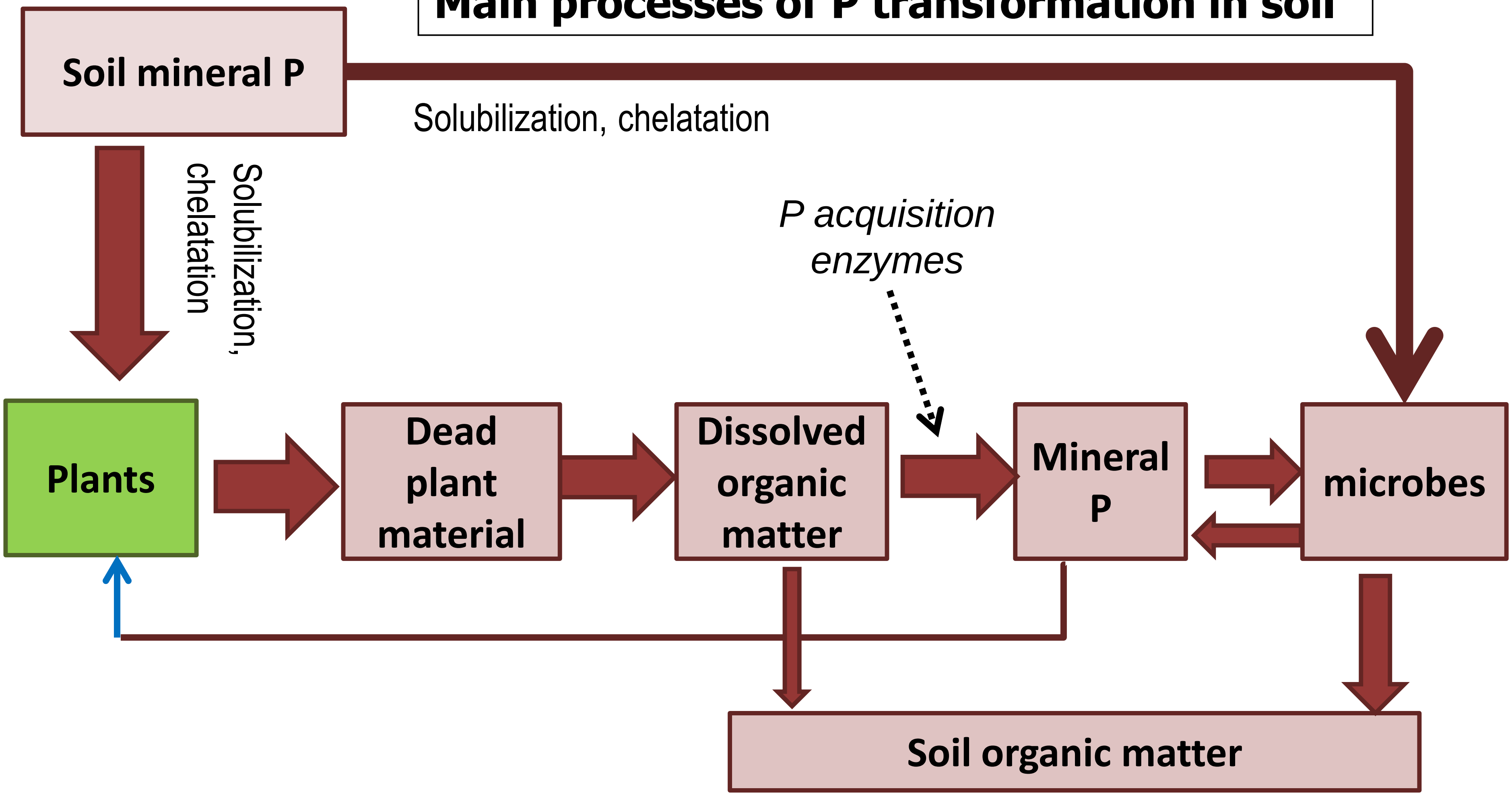
WHY?

Phosphorus transformations

P is an essential element of biomass

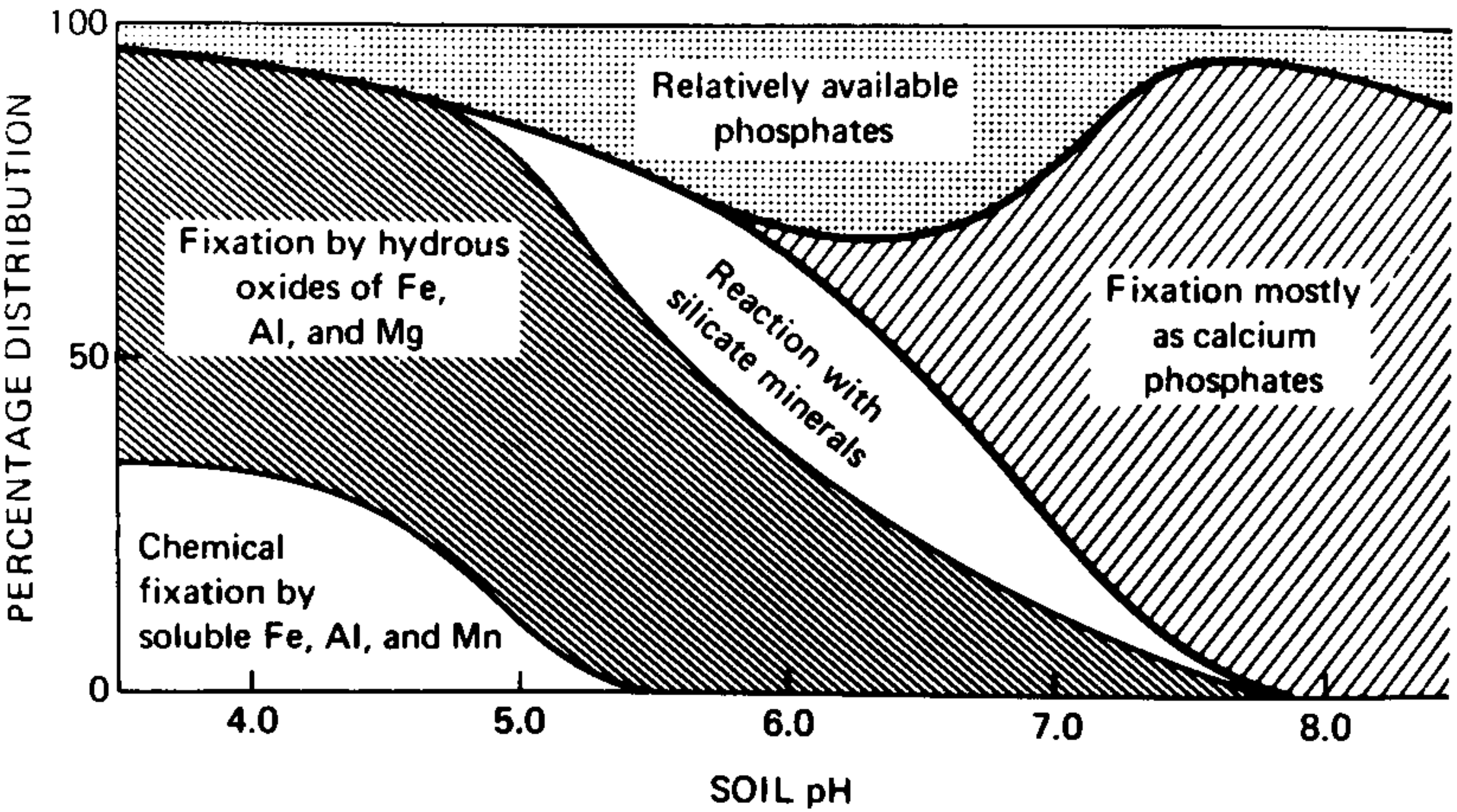


Main processes of P transformation in soil



Proportion between P mineralization and P immobilization to microbial biomass and SOM depends on resource to consumer stoichiometry, P availability and environmental conditions

Difficulty of P: it is available only at very narrow range of pH



Brady, N. C., & Weil, R. R. (2002). Soil phosphorus and potassium. *The Nature and Properties of Soils (13th Ed.). Upper Saddle River, NJ: Prentice-Hall, Inc*.

Take home message: never ever memorize only. Think of principles, causality and background of the processes