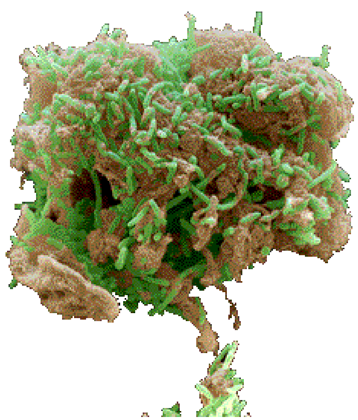
Faculty of Agronomy
Mendelova univerzita v Brně
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

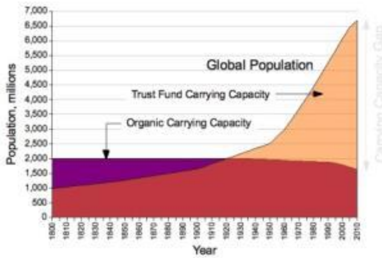
Sustainability of agriculture in the most vulnerable areas of water management (Březová nad Svitavou) – the use of biological methods of evaluation

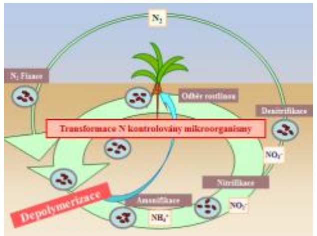
Plošek Lukáš, Záhora Jaroslav, Kintl Antonín, Elbl Jakub, Tůma Ivan, Hynšt Jaroslav, Urbánková Olga

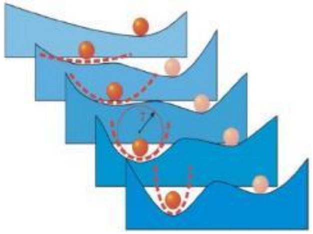


evropský sociální fond v ČR
OP Vzdělávání pro konkurenceschopnost
EUROPEAN UNION European Regional Development Fund
SONDAR CZ–AT Soil Strategy Network in the Danube Region
EUROPEAN TERRITORIAL CO-OPERATION AUSTRIA-CZECH REPUBLIC 2007-2013
Gemeinsam mehr erreichen. Společně dosáhneme více.

(a) Sustainability of agriculture

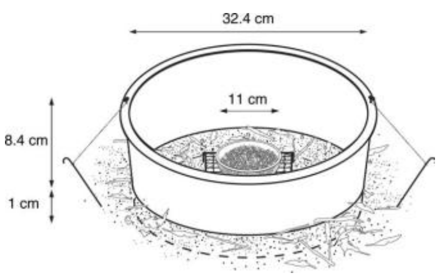




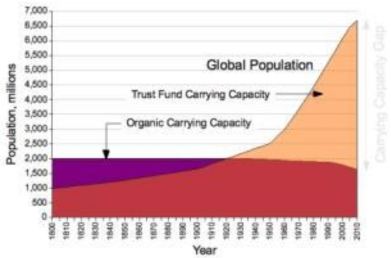


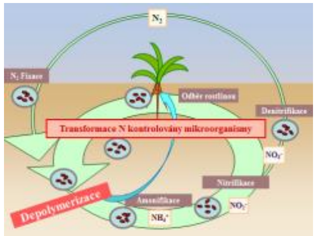
(b) The infiltration area

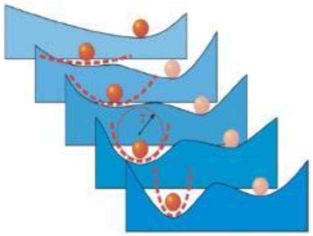
(c) Biological methods



(a) Sustainable agriculture







has been defined as

"an integrated system of plant and animal production practices having a site-specific application that will last over the long term“.

The carrying capacity

Pieter Bruegel the Elder- The Corn Harvest (August)

Carrying capacity ……. the extent to which the natural environment is able to tolerate and regenerate the interference and damage from agriculture.

The number of cattle (per 1ha) that could be maintained on grassland **sustainable**, e.g. without degrading the land so that it could no longer support the animals.

Biomass of soil organisms 1% of the soil weight

(globally 57% of terrestrial biomass)

Microorganisms - 1% of the soil weight (57% of terrestrial biomass)

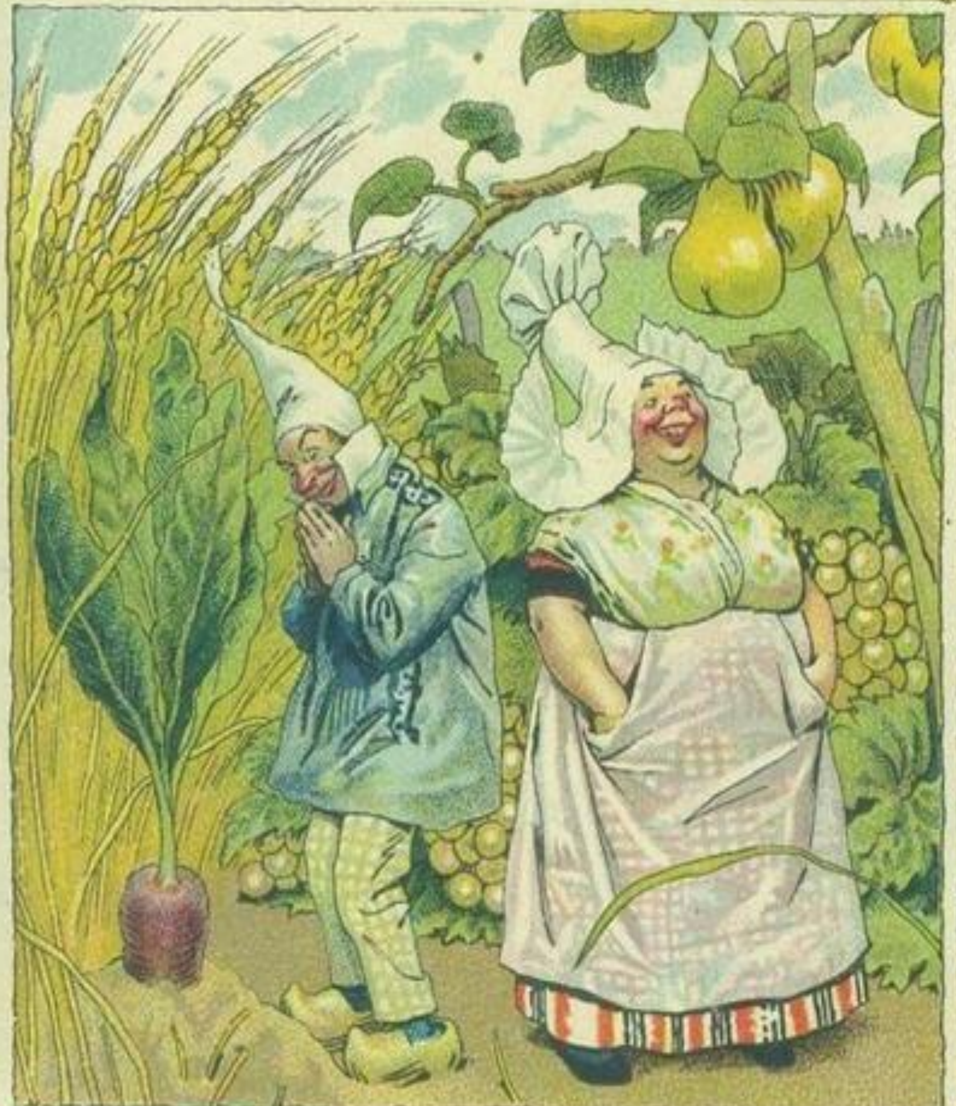
Grazing livestock beyond the CC .. Livestock Units (LUs)

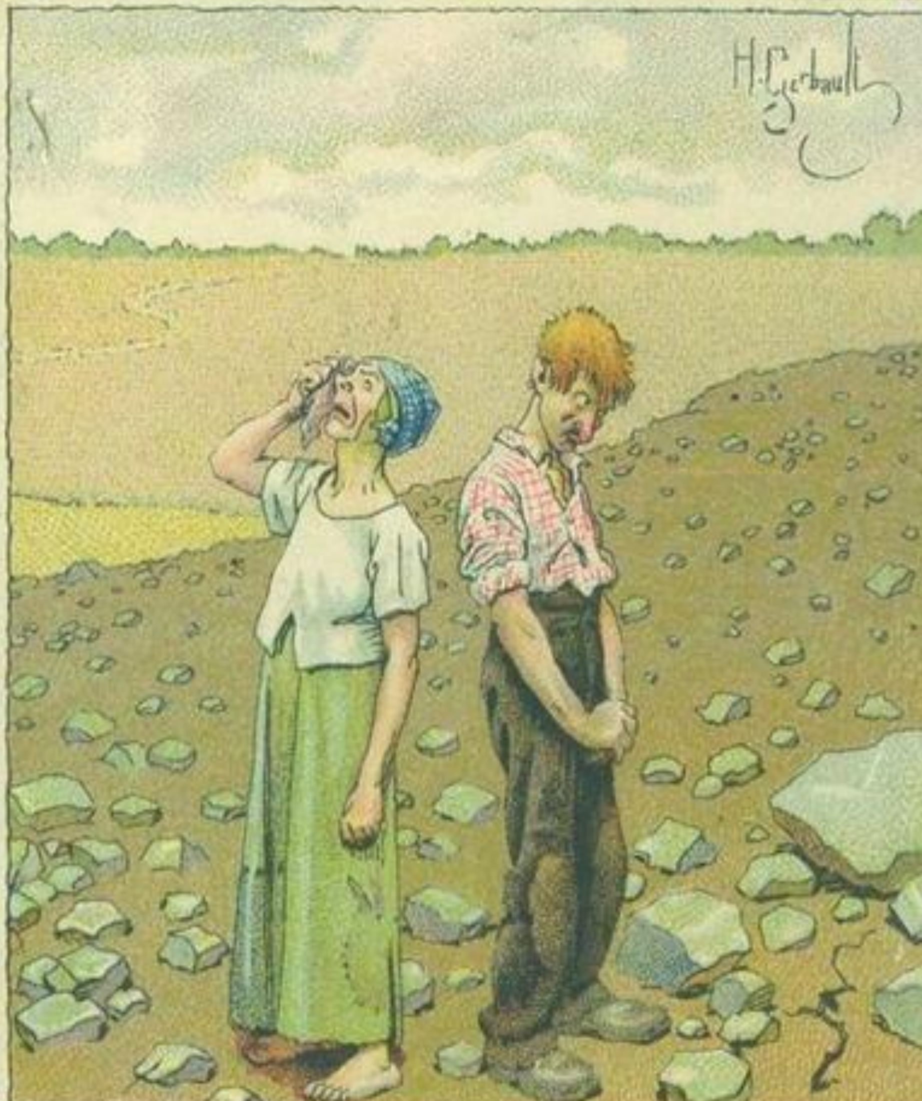
Overcoming the carrying capacity threshold

Justus Freiherr von Liebig[2] (12 May 1803 – 18 April 1873) is considered the "**father of the fertilizer industry**" for his discovery of nitrogen as an essential plant nutrient.

He **downplayed the role of humus** in plant nutrition and discovered that plants feed on nitrogen compounds and carbon dioxide derived from the air, as well as on minerals in the soil.

AVEC SULFATE D'AMMONIAQUE	SANS SULFATE D'AMMONIAQUE





" Les Agriculteurs français, soucieux du progrès, doivent employer comme **ENGRAIS AZOTÉ**, dans toutes les cultures et sur tous les sols, **LE SULFATE D'AMMONIAQUE** "

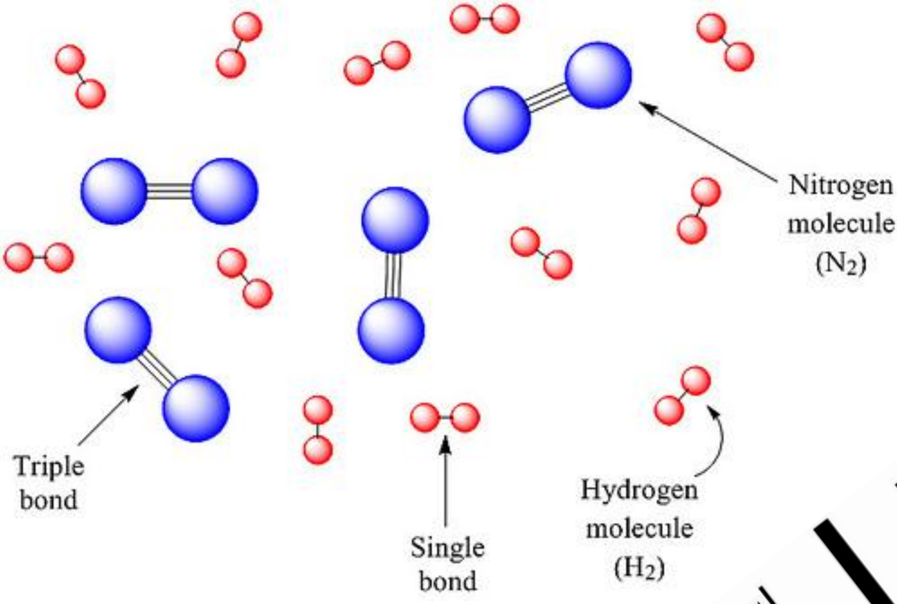
Tadeas Peregrinus Xaverius Haenke (Hänke)

A Czech who lived in Latin America, was the one who gave the first impulse in 1809 to the exploitation of nitrate by converting the sodium nitrate into potassium nitrate, from the Caliche of Tarapacá".

The Haber-Bosch process

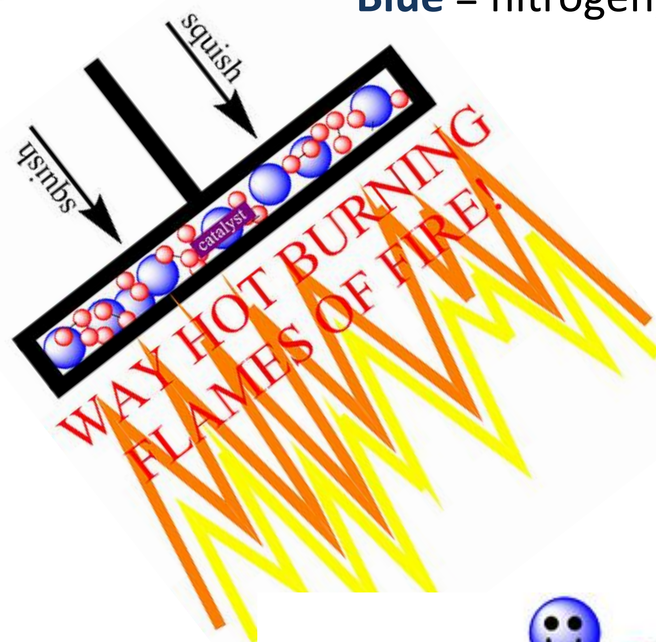
the most important scientific discovery ever

(*in terms of having a direct impact on the largest amount of people*)

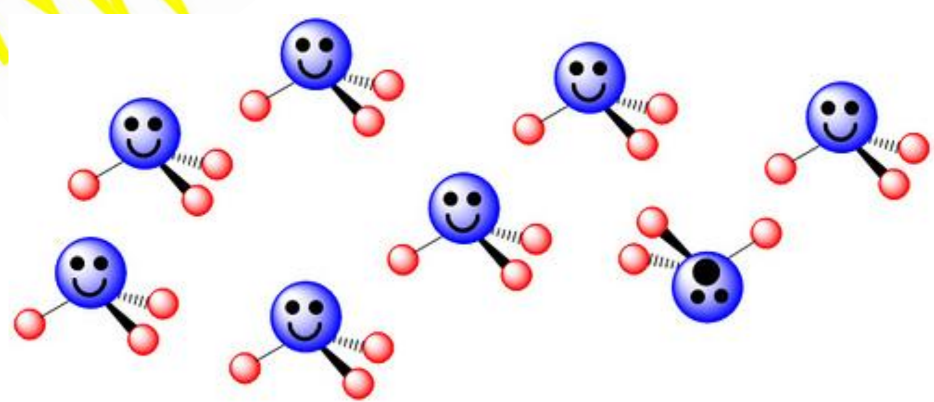


Nitrogen and hydrogen gasses

Blue = nitrogen, **red** = hydrogen

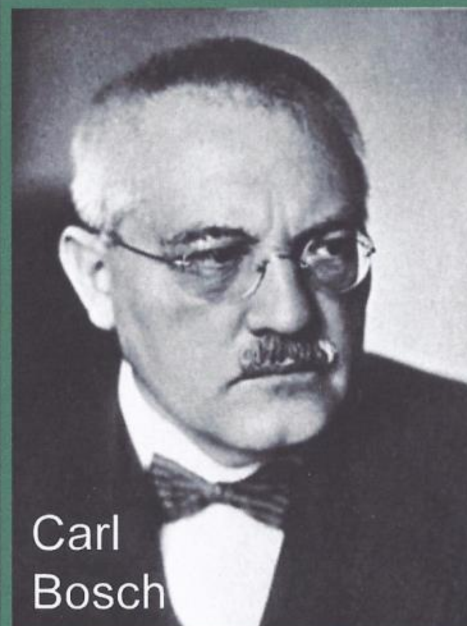


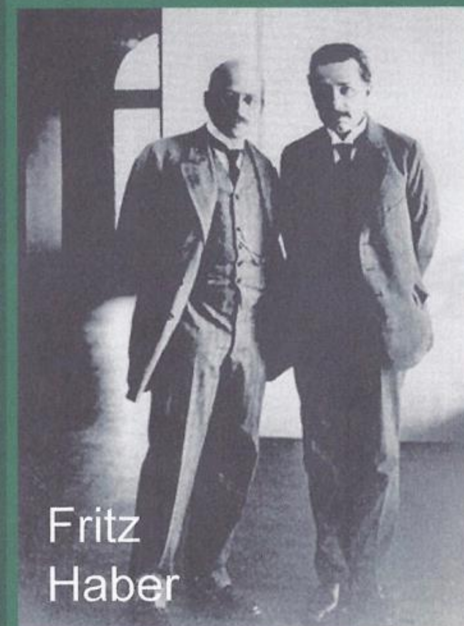
The Haber-Bosch process was developed in the early 20th century to combine nitrogen from the air with hydrogen at high temperature and pressure to make ammonia (NH3), the basis for all synthetic nitrogen fertilizers as well as munitions used in warfare.



Solution – Synthetic Nitrogen
A BASF discovery

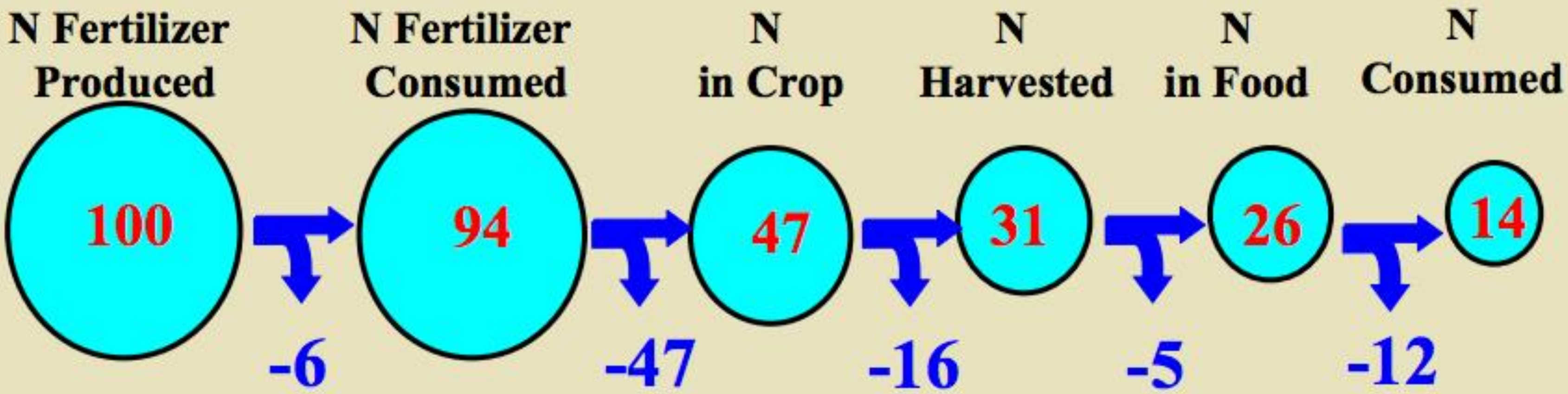
BASF
The Chemical Company





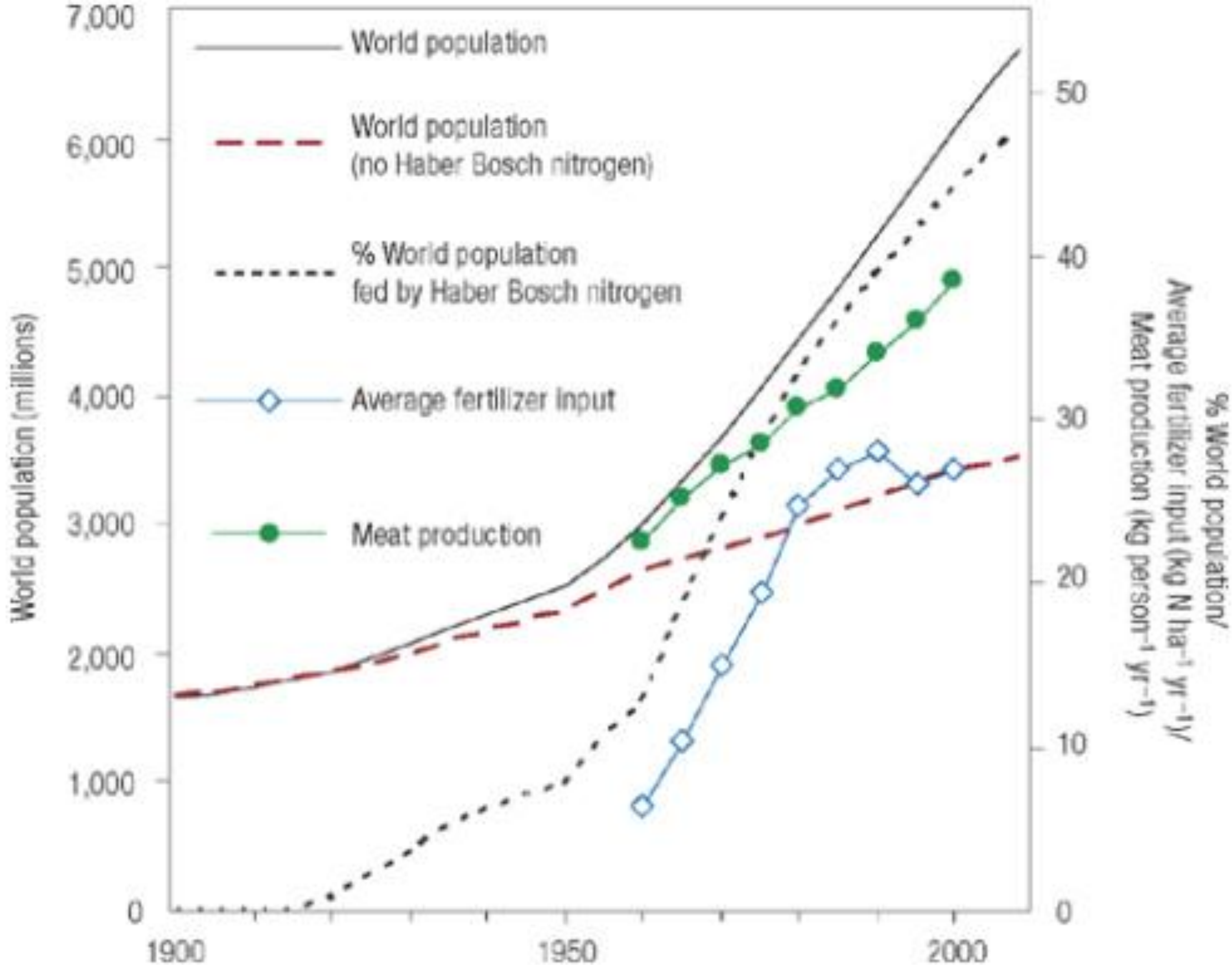
"….Without this discovery the earth would only sustain 4 billion people"

The Fate of Haber-Bosch Nitrogen

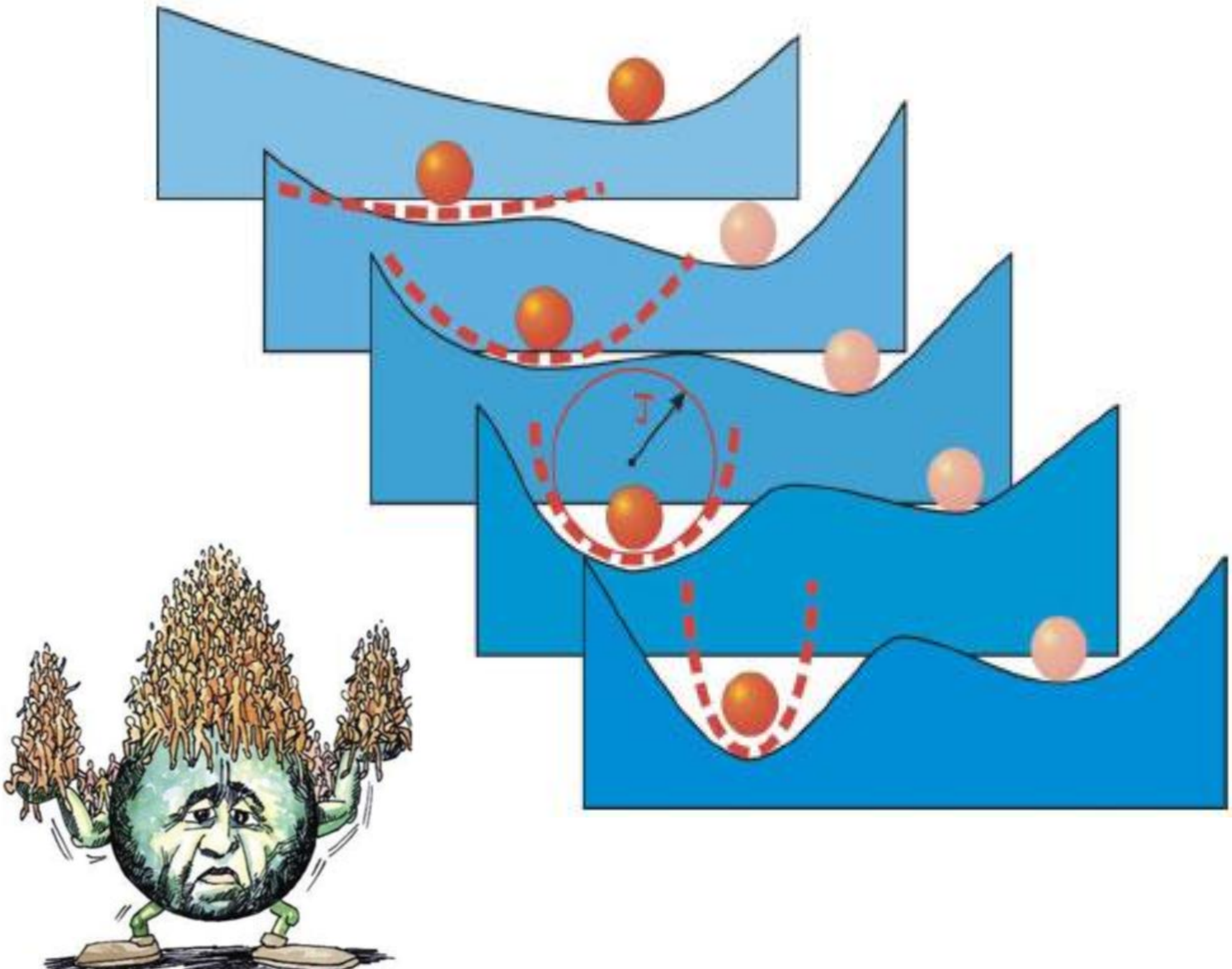


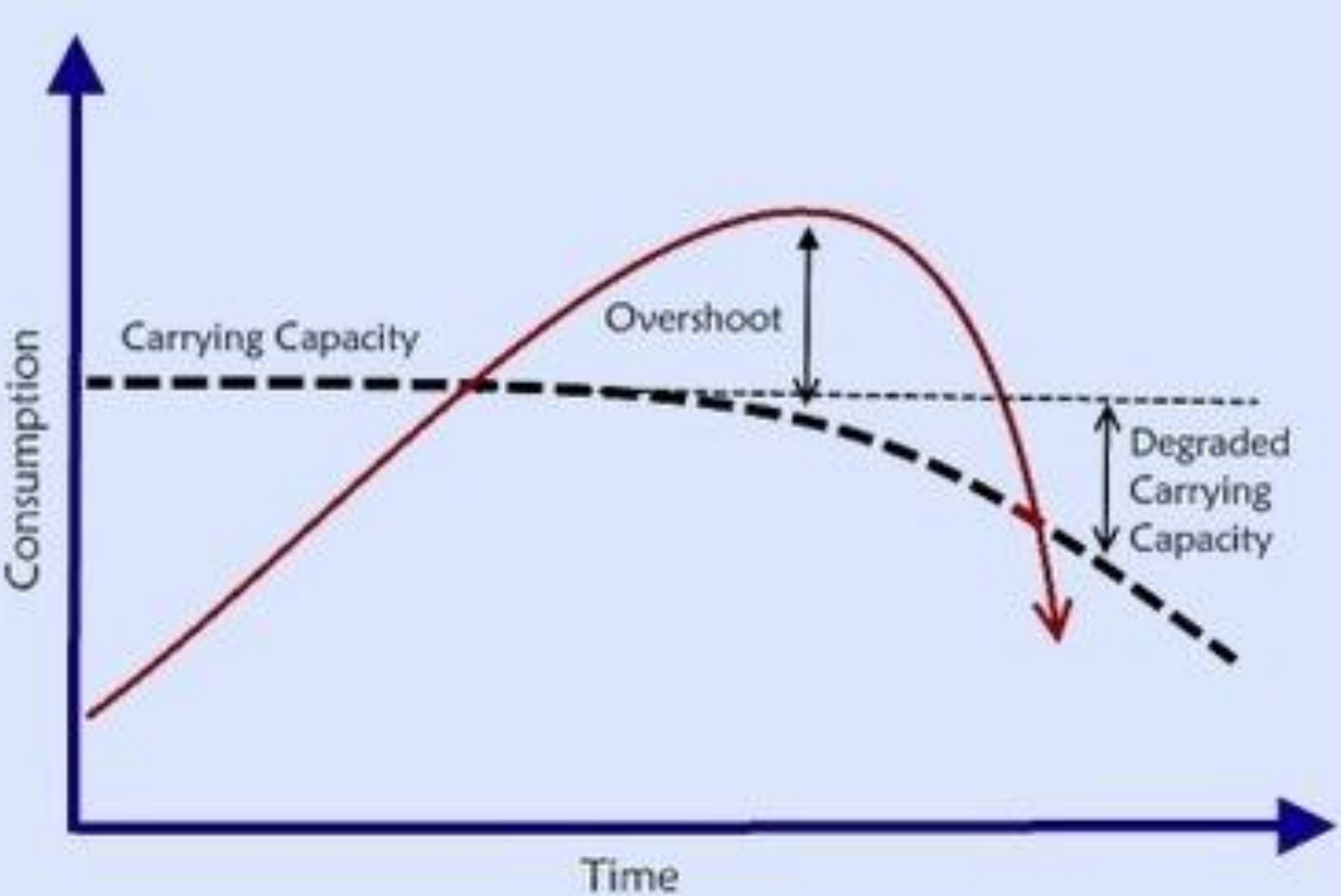
14% of the N produced in the Haber-Bosch process enters the human mouth………if you are a vegetarian. The remainder is lost to the environment.

Galloway JN and Cowling EB. 200

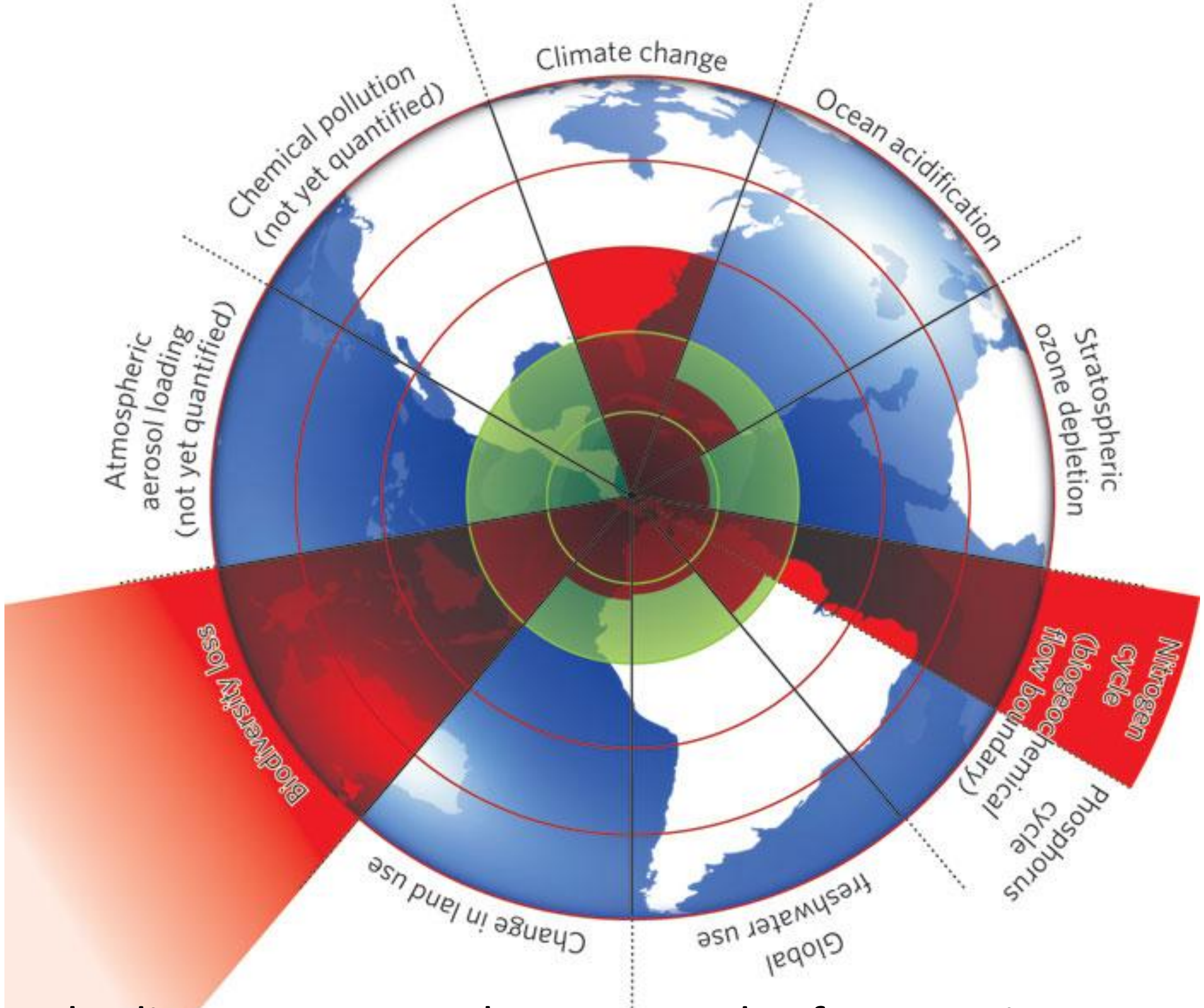


Effect of the Haber-Bosch process on world population. Graph from Erisman, J. W.; Sutton, M. A.; Galloway, J.; Klimont, Z.; Winiwarter, W. “How a Century of Ammonia Synthesis Changed the World”. Nat. Geosci. 2008, 1: 636-630.


J



Consumption
Carrying Capacity
Overshoot
Degraded
Carrying
Capacity
Time



The inner green shading represents the proposed safe operating space for nine planetary systems. The red wedges represent an estimate of the current position for each variable.

The boundaries in three systems (rate of biodiversity loss, climate change and human interference with the nitrogen cycle), have already been exceeded.

A safe operating space for humanity Johan Rockström et al., Nature 461, 472-475(24 September 2009)

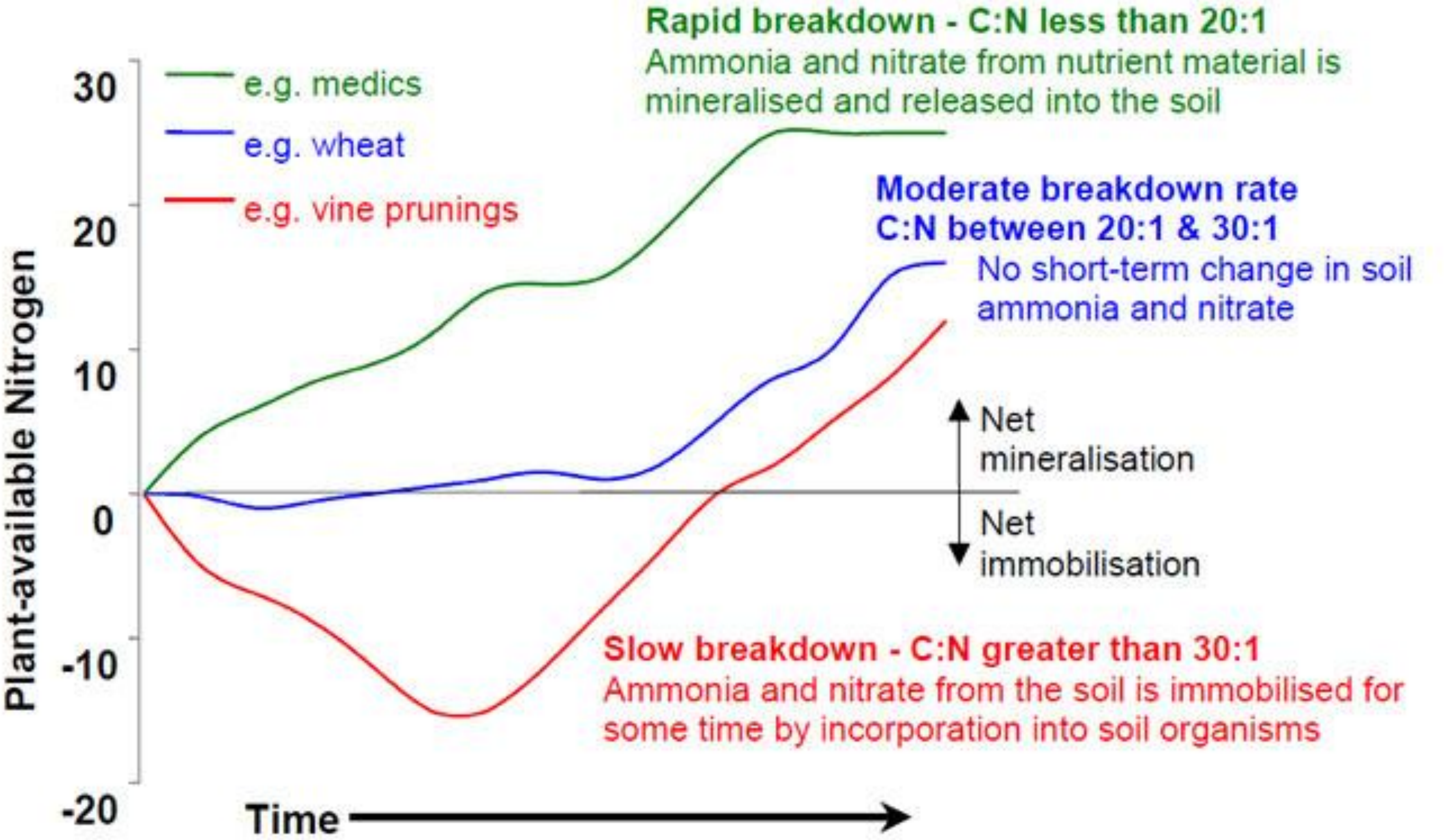
PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status		Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	**3.**	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5		0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	**1.**	0.1-1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	**2.**	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5-9.5		~1

The planetary boundary for nitrogen cycle have already been 3.5 times exceeded

A safe operating space for humanity Johan Rockström et al., Nature 461, 472-475(24 September 2009)

C : N ratio



C:N ratio and plant available nitrogen (Treeby et Goings, 2001)

Solely application of mineral N

Solely application of mineral N

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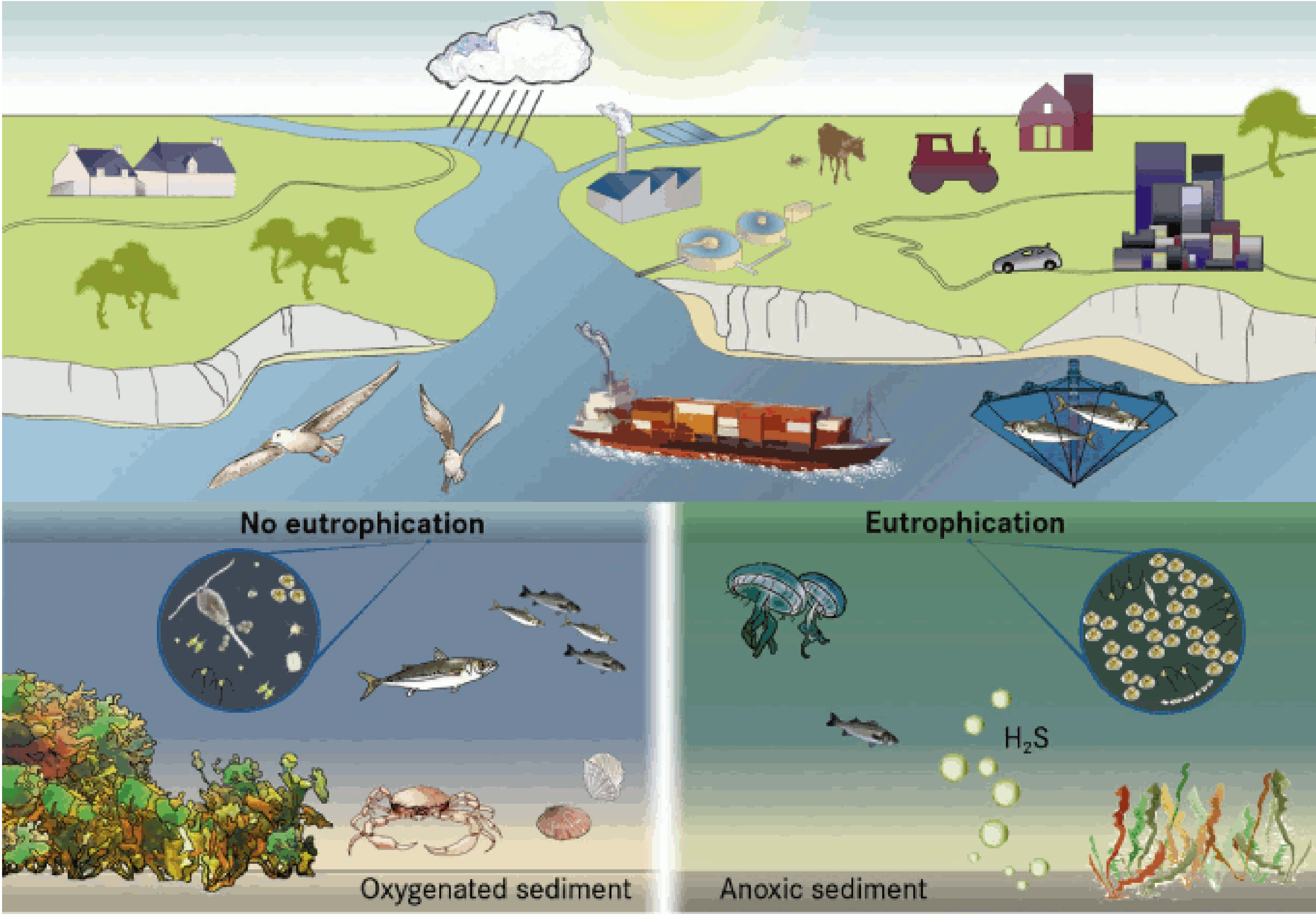
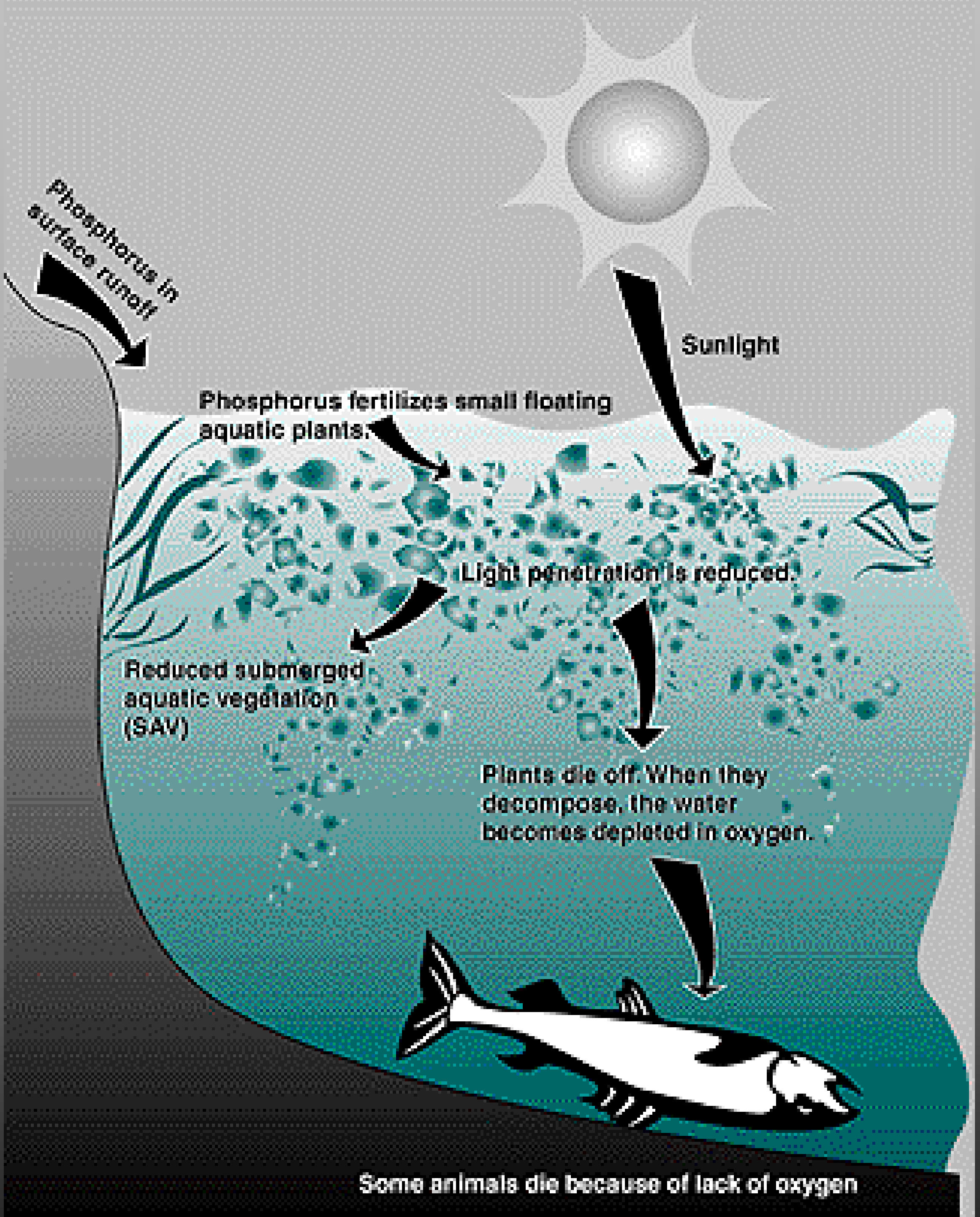
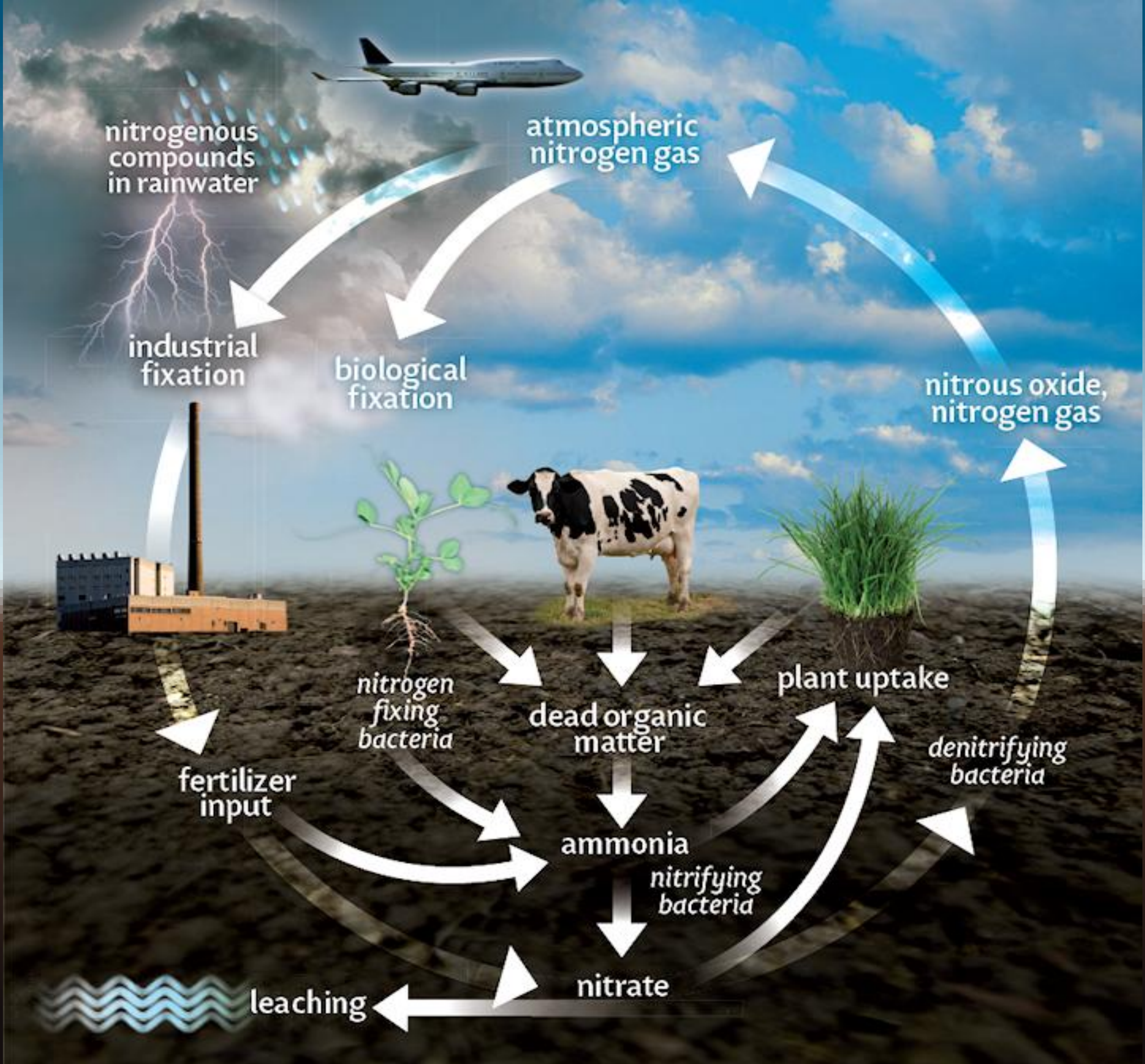


No eutrophication
Eutrophication
H_2S
Oxygenated sediment
Anoxic sediment


Phosphorus in surface runoff
Sunlight
Phosphorus fertilizes small floating aquatic plants.
Light penetration is reduced.
Reduced submerged aquatic vegetation (SAV)
Plants die off. When they decompose, the water becomes depleted in oxygen.
Some animals die because of lack of oxygen

Reaching toward the goal of sustainable agriculture is the responsibility of all participants in the system, including farmers, policymakers etc. …..

(b) The infiltration area



nitrogenous compounds in rainwater
atmospheric nitrogen gas
industrial fixation
biological fixation
nitrous oxide, nitrogen gas
nitrogen fixing bacteria
dead organic matter
plant uptake
denitrifying bacteria
fertilizer input
ammonia
nitrifying bacteria
nitrate
leaching

The area for the supply of drinking water

Preliminary results:

Comparing mineral nitrogen output from different ecosystem during the 5 yaers

What is the proportion of arable land in leaching of nitrogen? (based on the surface area which represents cca 80%)

Proportion of grasslands and forests?

Arable soil


Arable soil

Arable soil

Forest soil


Forest soil

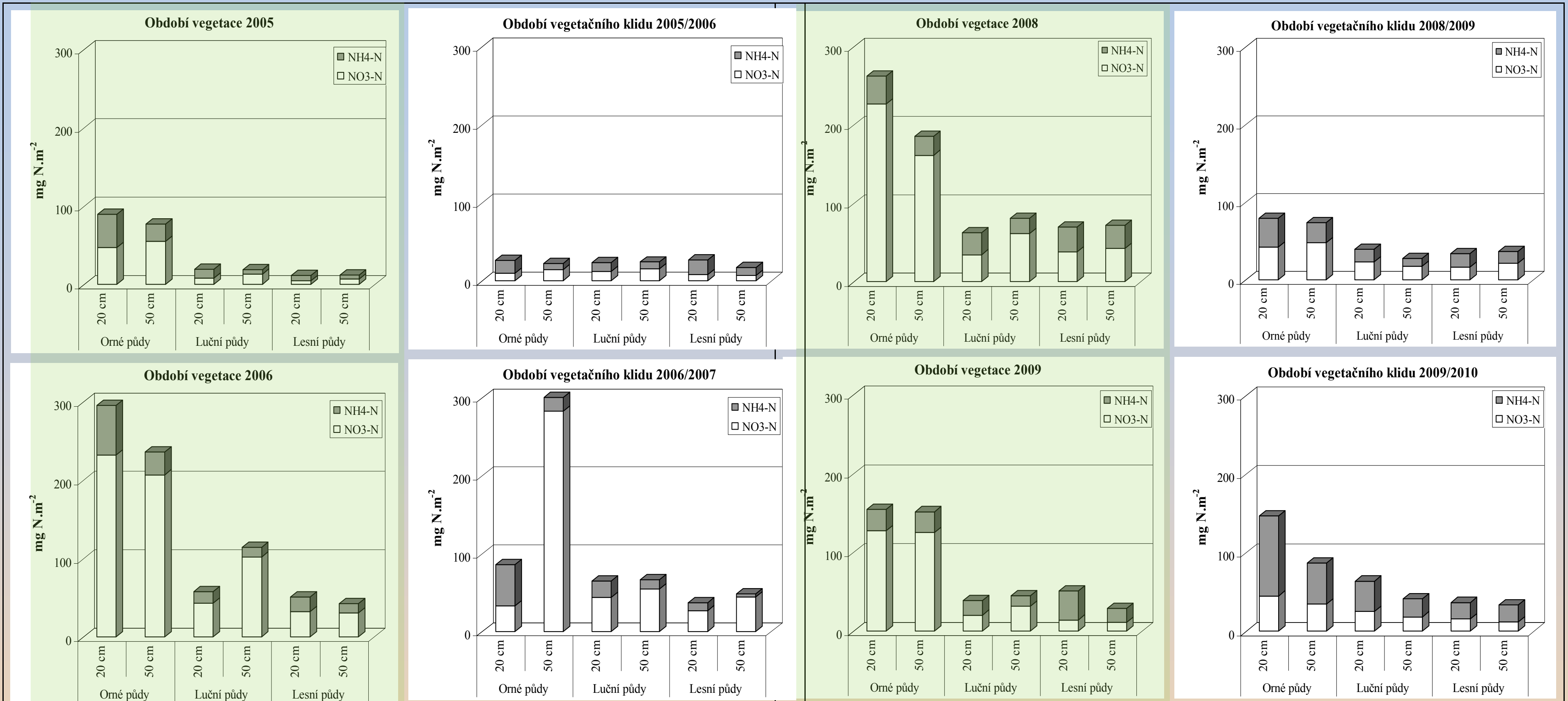
Forest soil

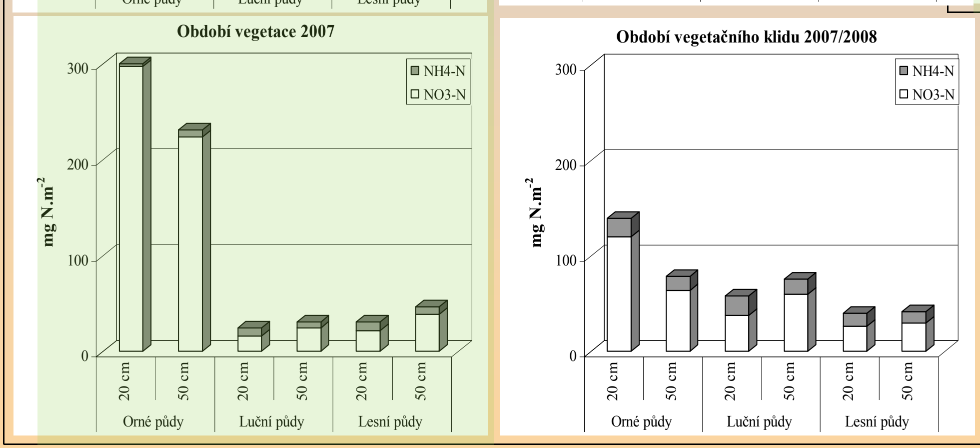
Meadow soil

Meadow soil

Meadow soil

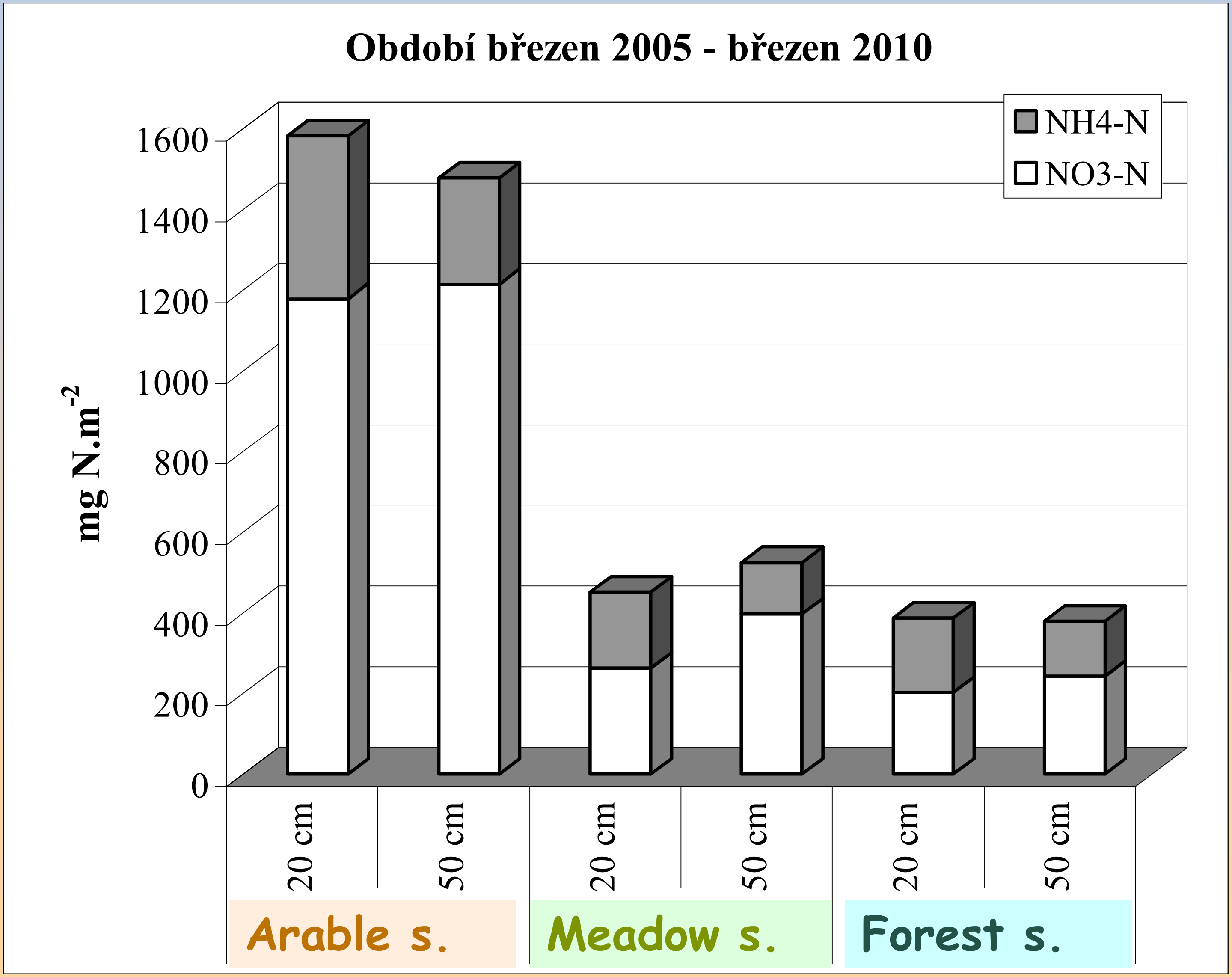
Meadow soil



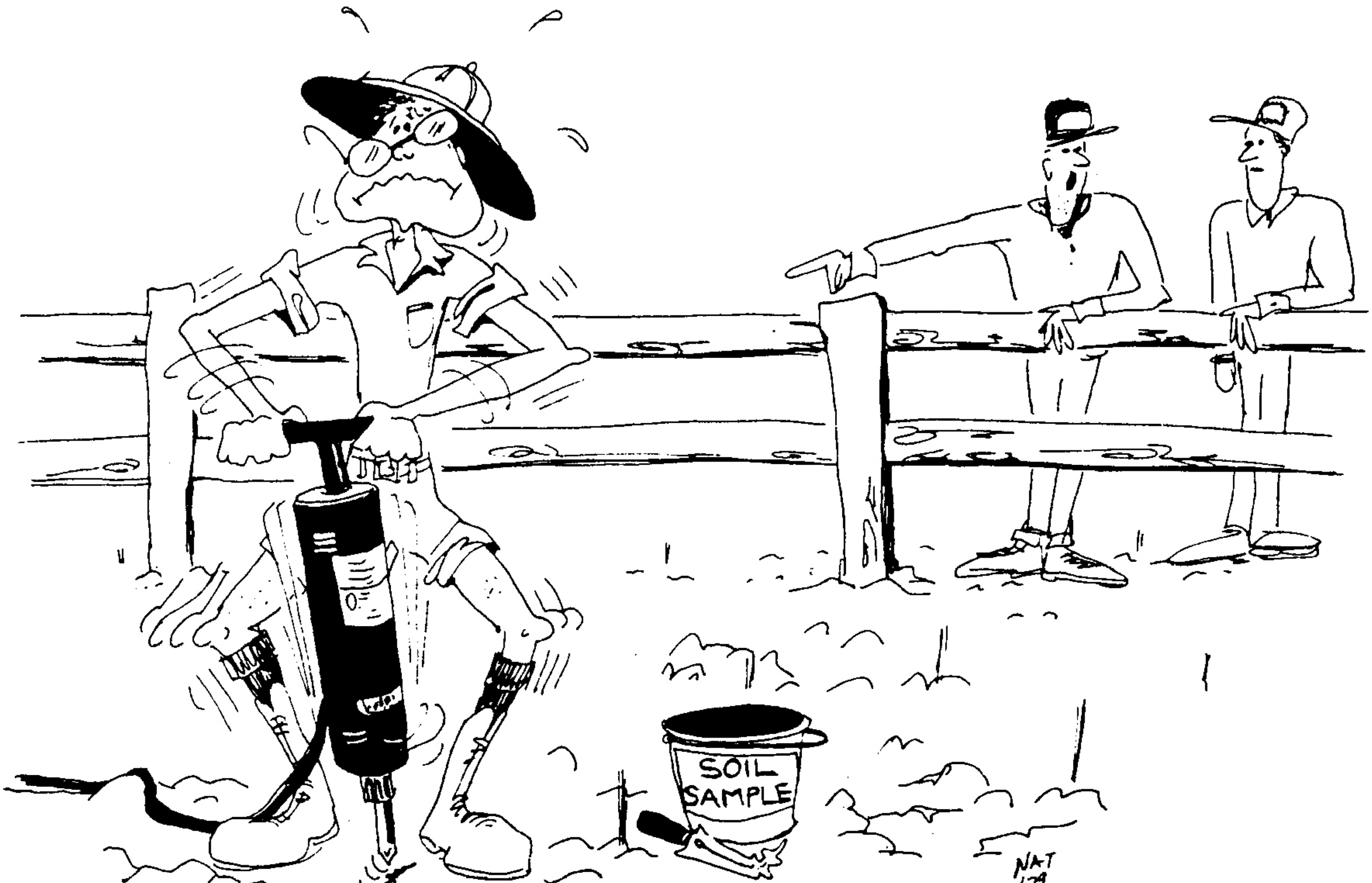


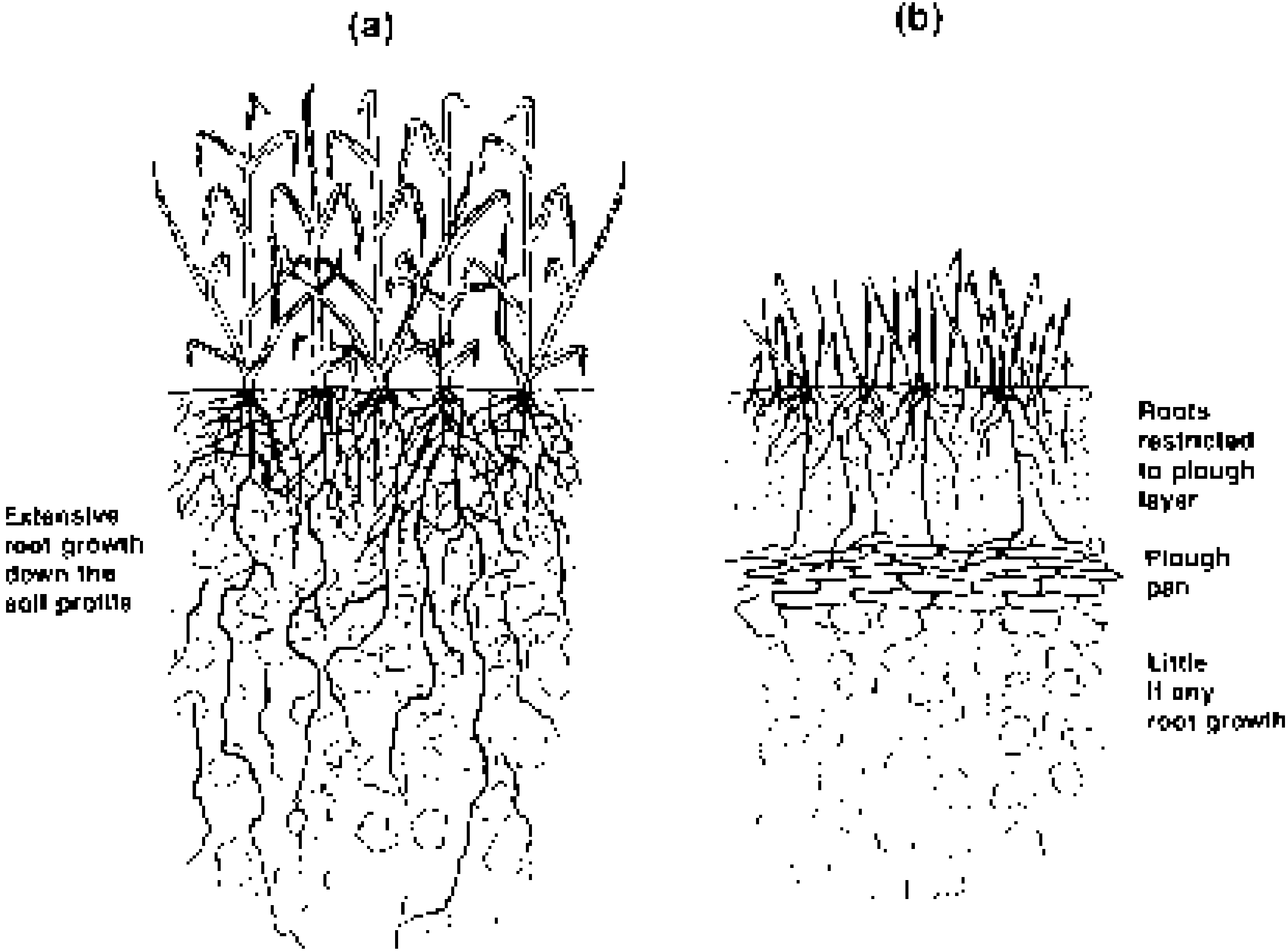
Cumulative trapping of mineral N in IER discs which were inserted into two depths (20 cm and 50 cm) in soils from three different ecosystems during vegetative and non-veg. seasons between 2005 and 2010 years

Shallow groundwater from arable lands percolating elsewhere ….



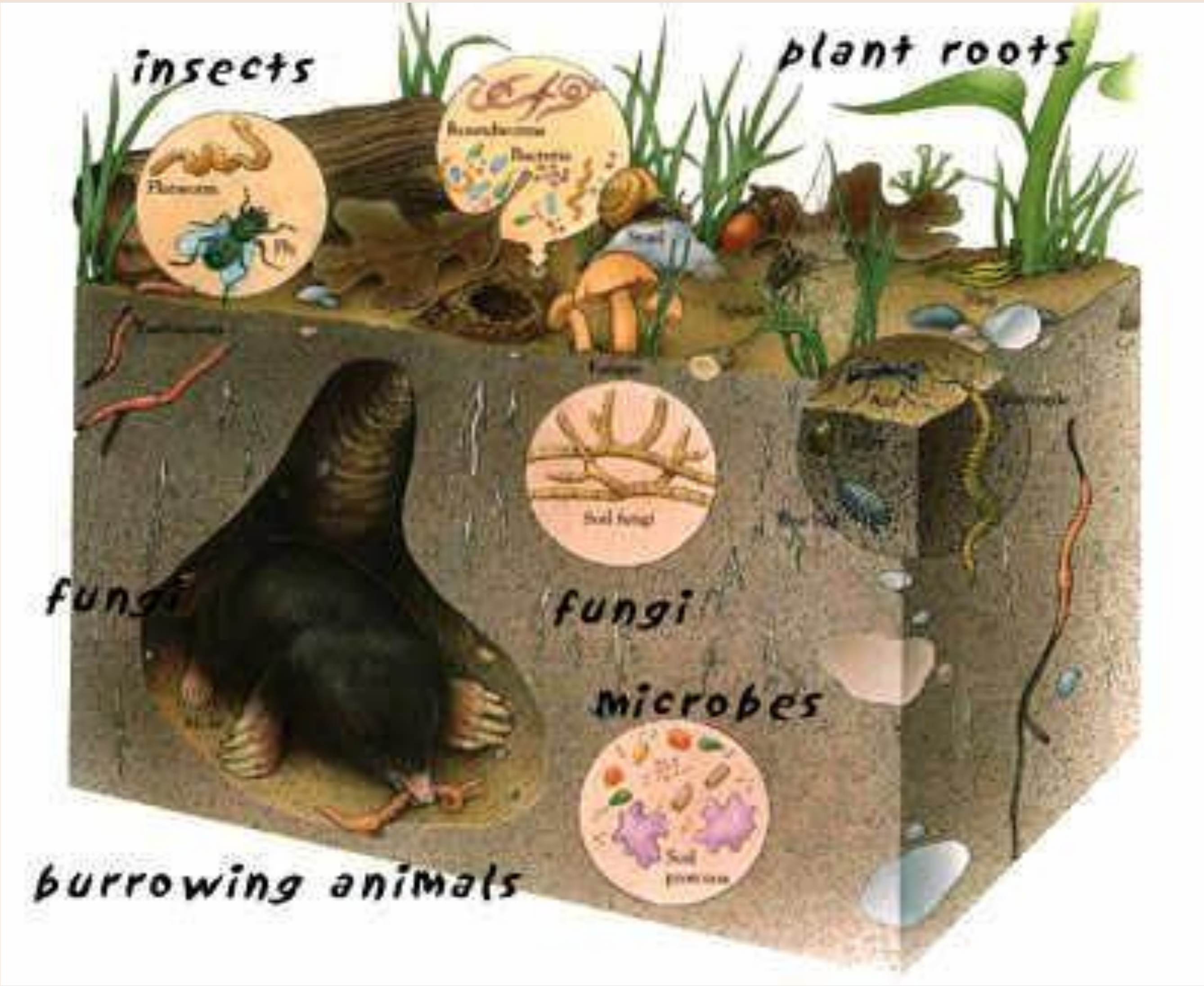
Subsurface groundwater flow significantly interconnects the soil environment in that area


SOIL
SAMPLE
NAT
'79



Subsoil compaction


Standard
520/85R 46
30 psi
Rut Depth: 10"

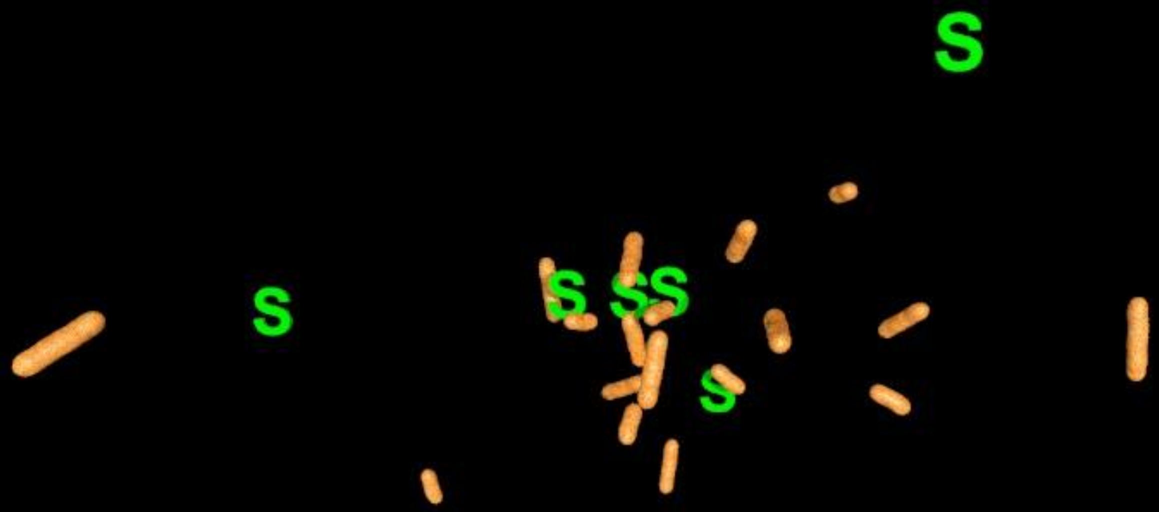


„Soil is the most complicated biomaterial on the planet.

As with any material, the physical habitat is of prime importance in determining and regulating biological activity.“

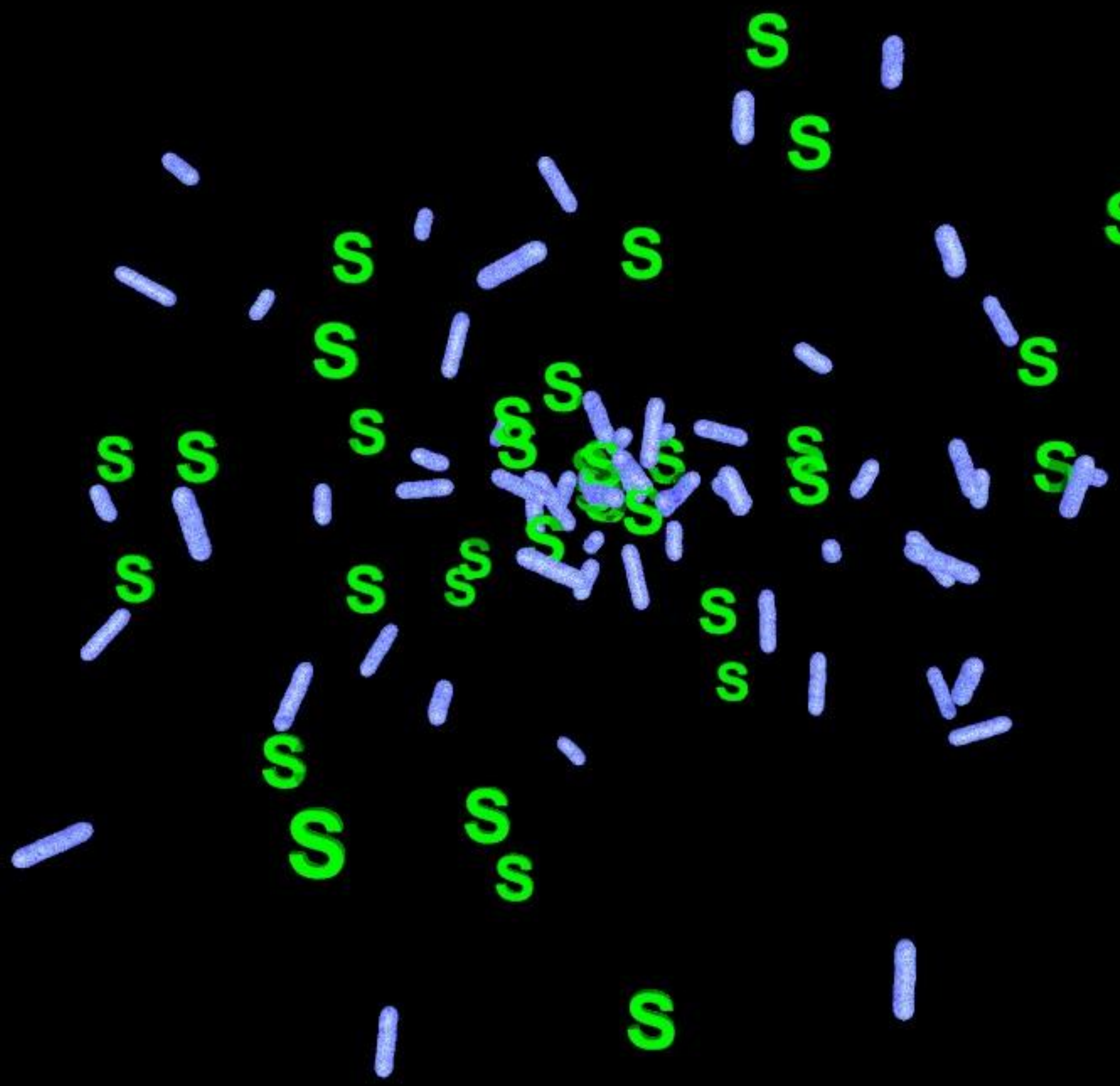
(Young and Crawford, 2004: Interactions and Self-Organization in the Soil-Microbe Complex)

Bacteria can communicate with each other by producing chemical signals.

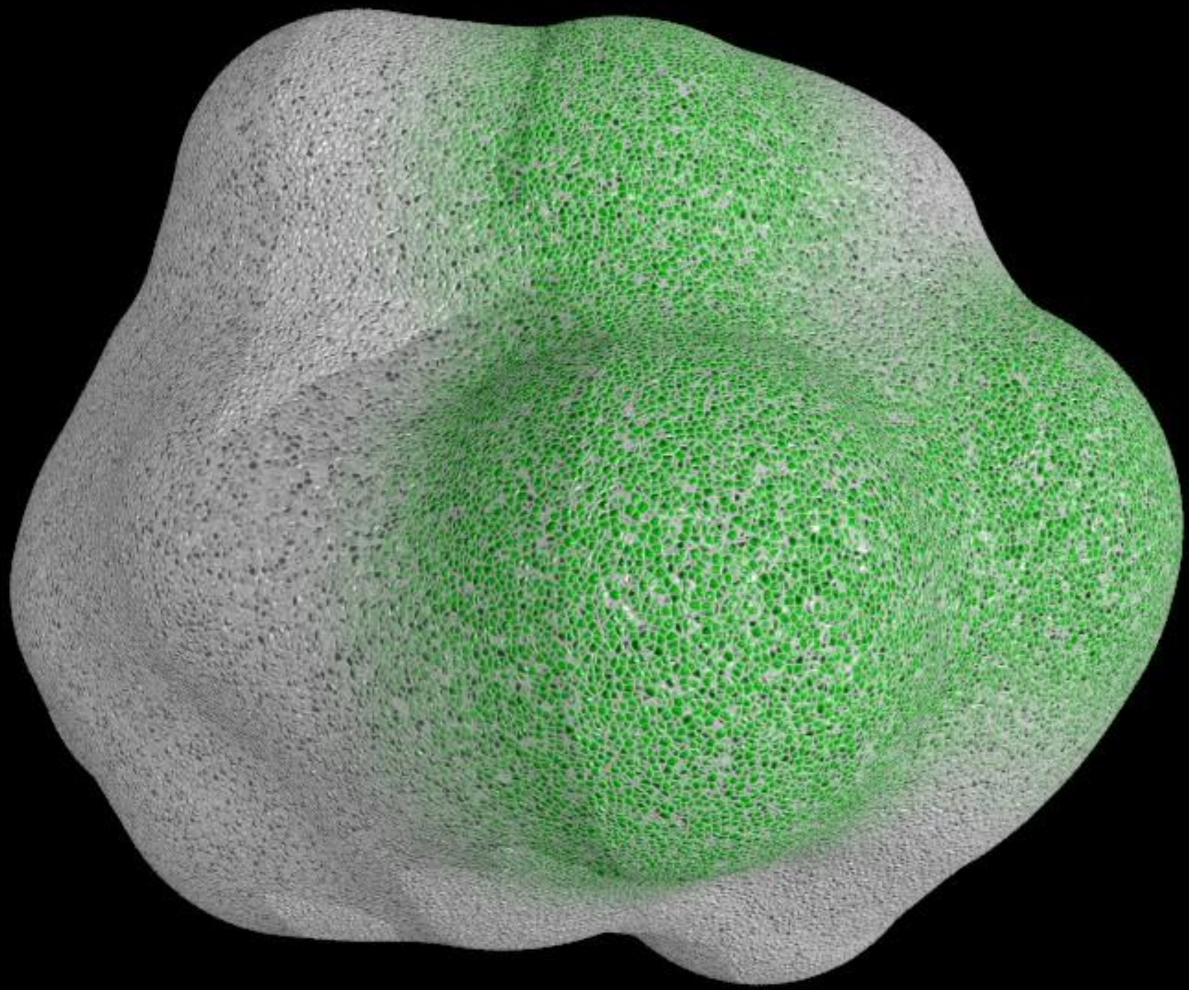


Higher densities of bacteria result in more signal molecules being produced.

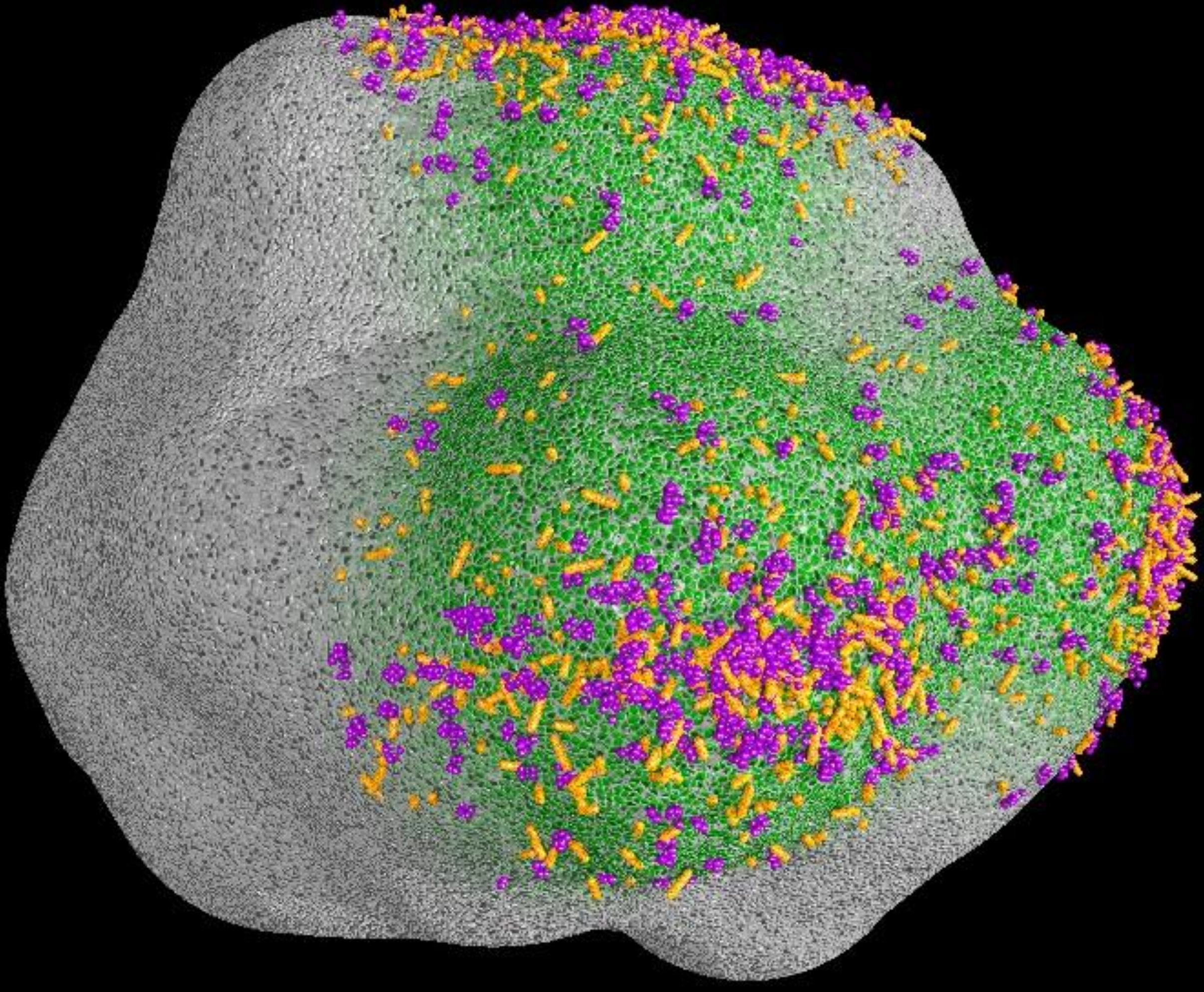
Once the concentration of signal molecules exceeds a certain threshold, the bacteria may change their behaviour (e.g., start producing toxic or protective compounds).



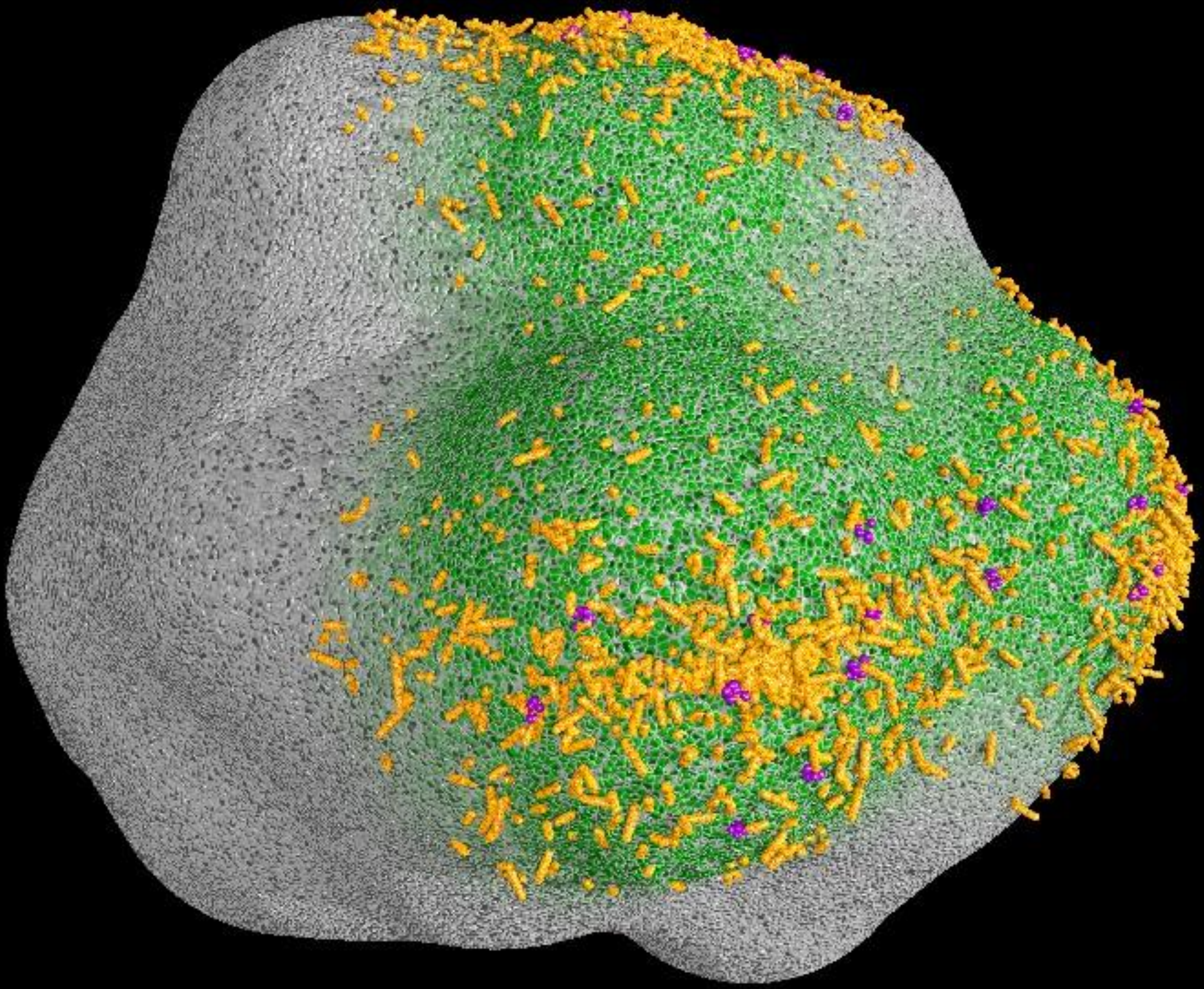
Now, let us assume, this is some chunk of organic material, consisting of cell walls and occasionally bound mineral nutrients.



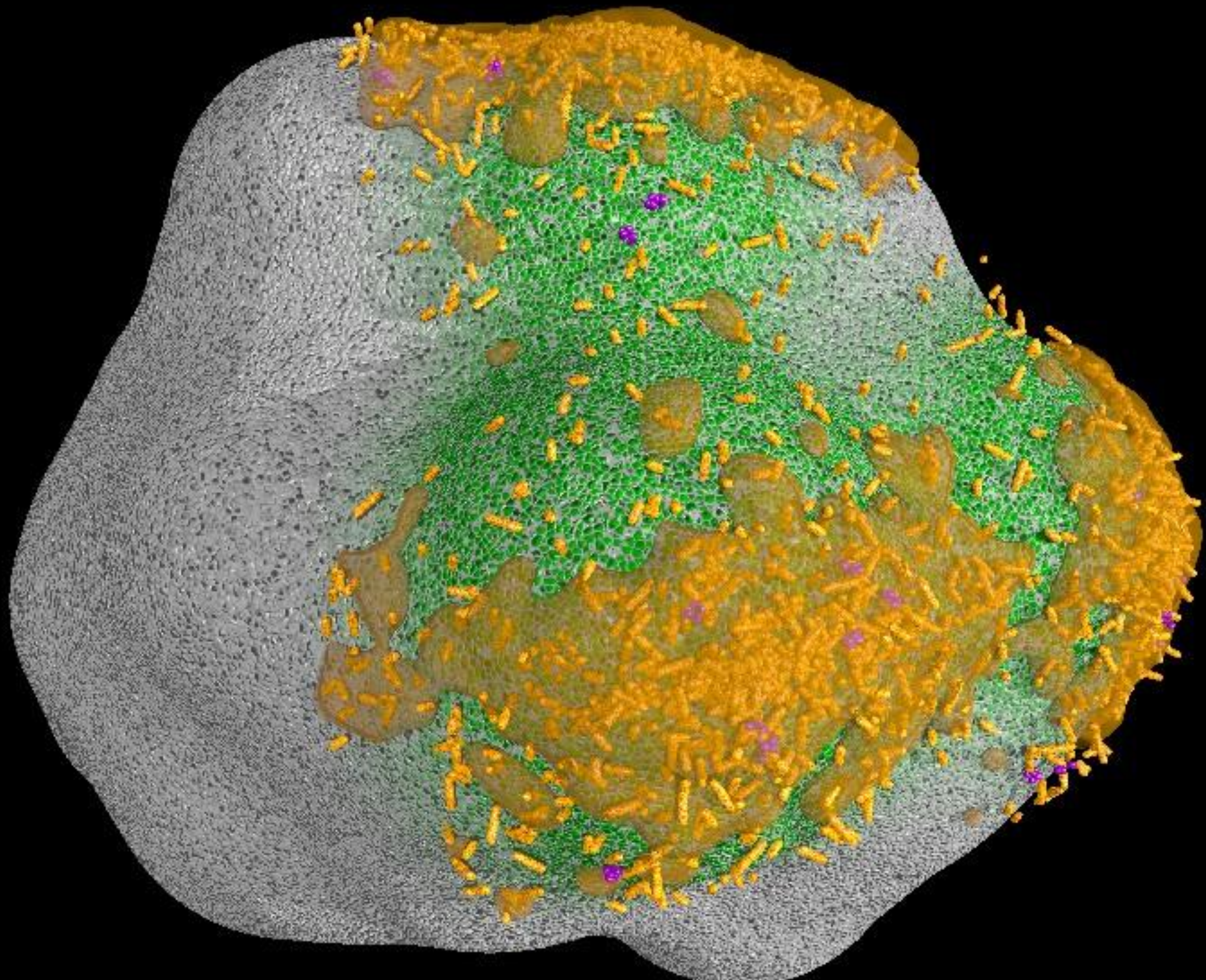
Bacteria will eventually reach the surface of this chunk. They will multiply at places providing sufficient nutrients.



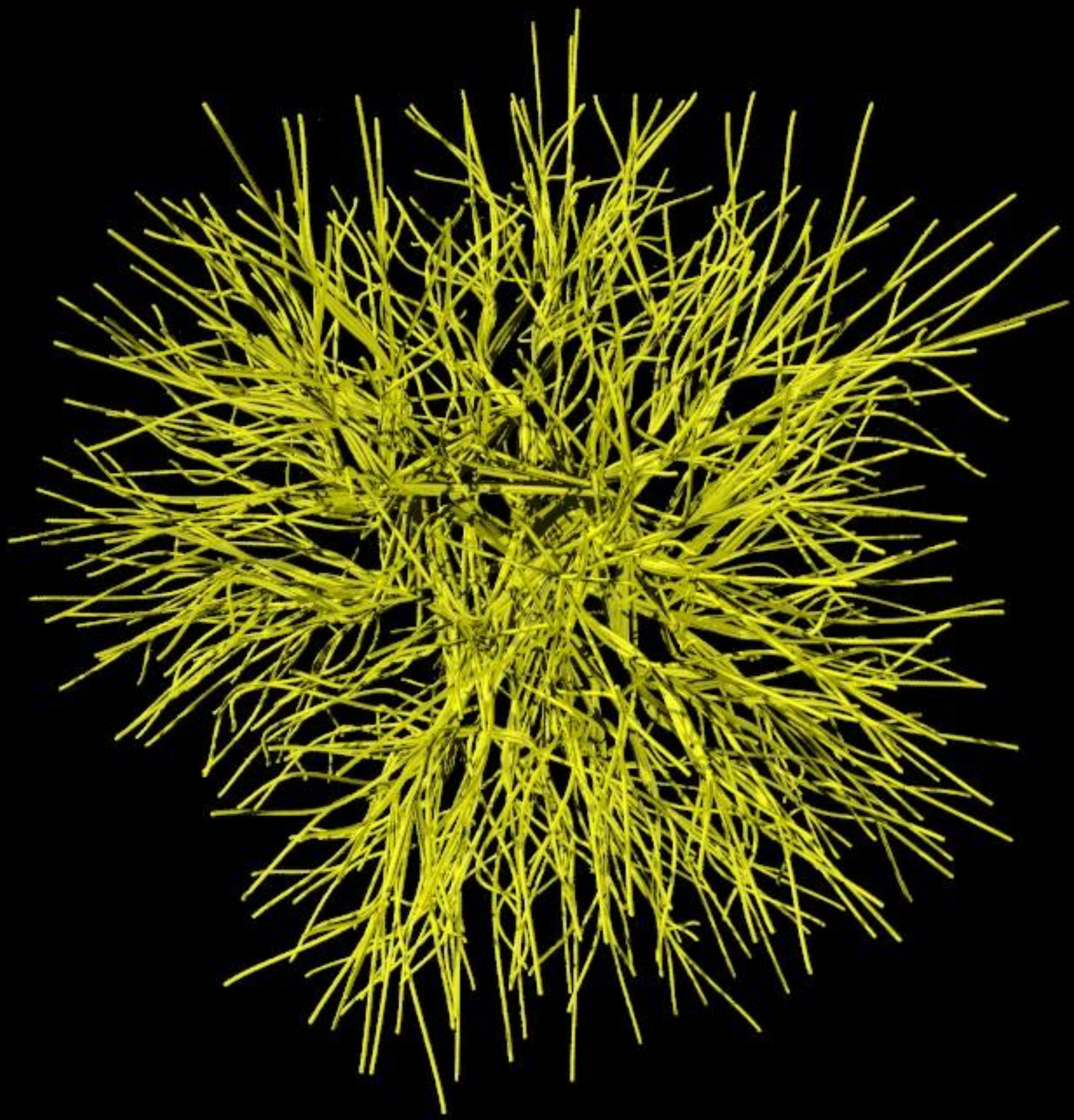
Some bacteria may produce toxic compounds, this way eliminating their competitors.



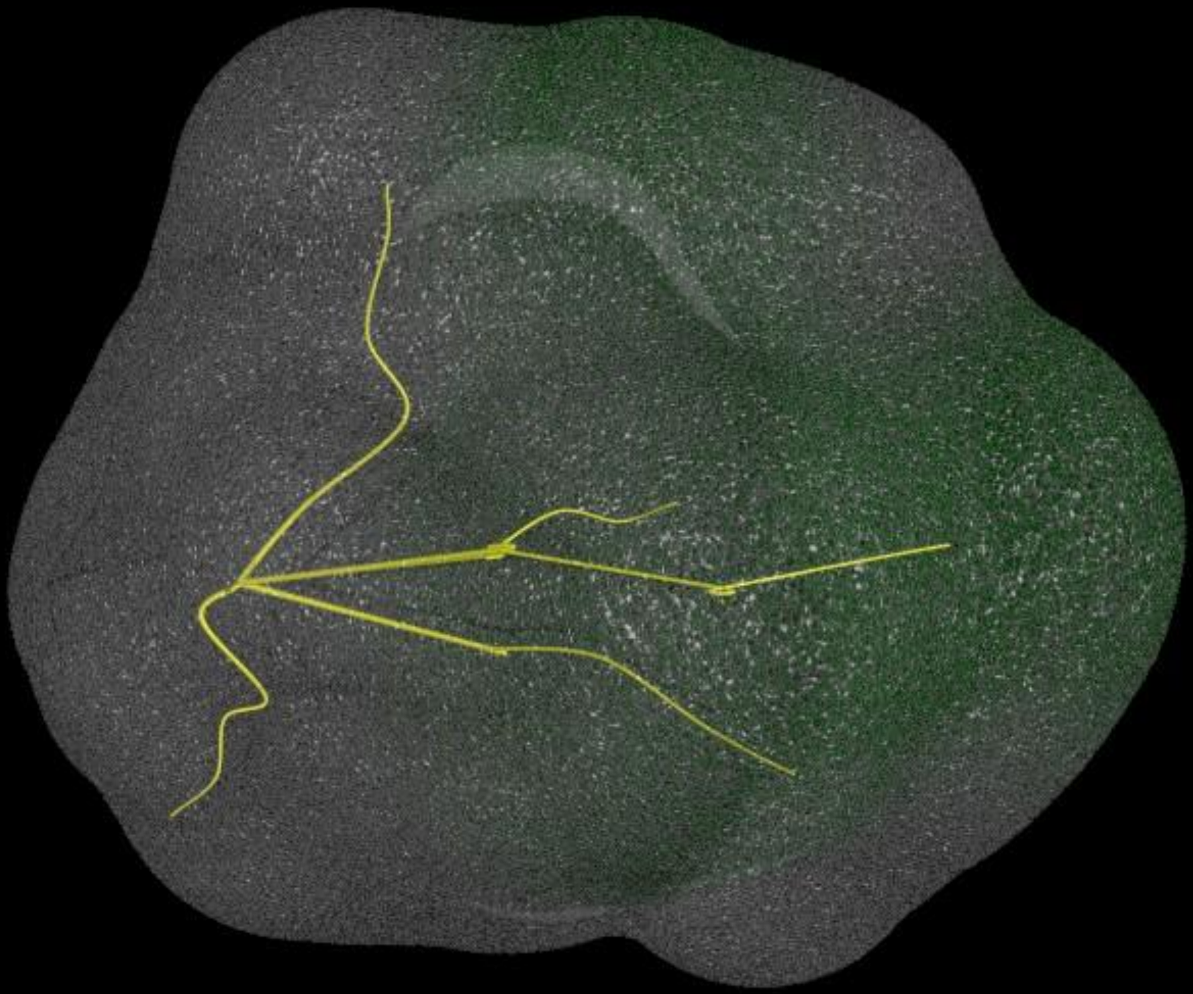
Once they have reached sufficient densities, some bacteria may produce protective mucous material (biofilm formation).



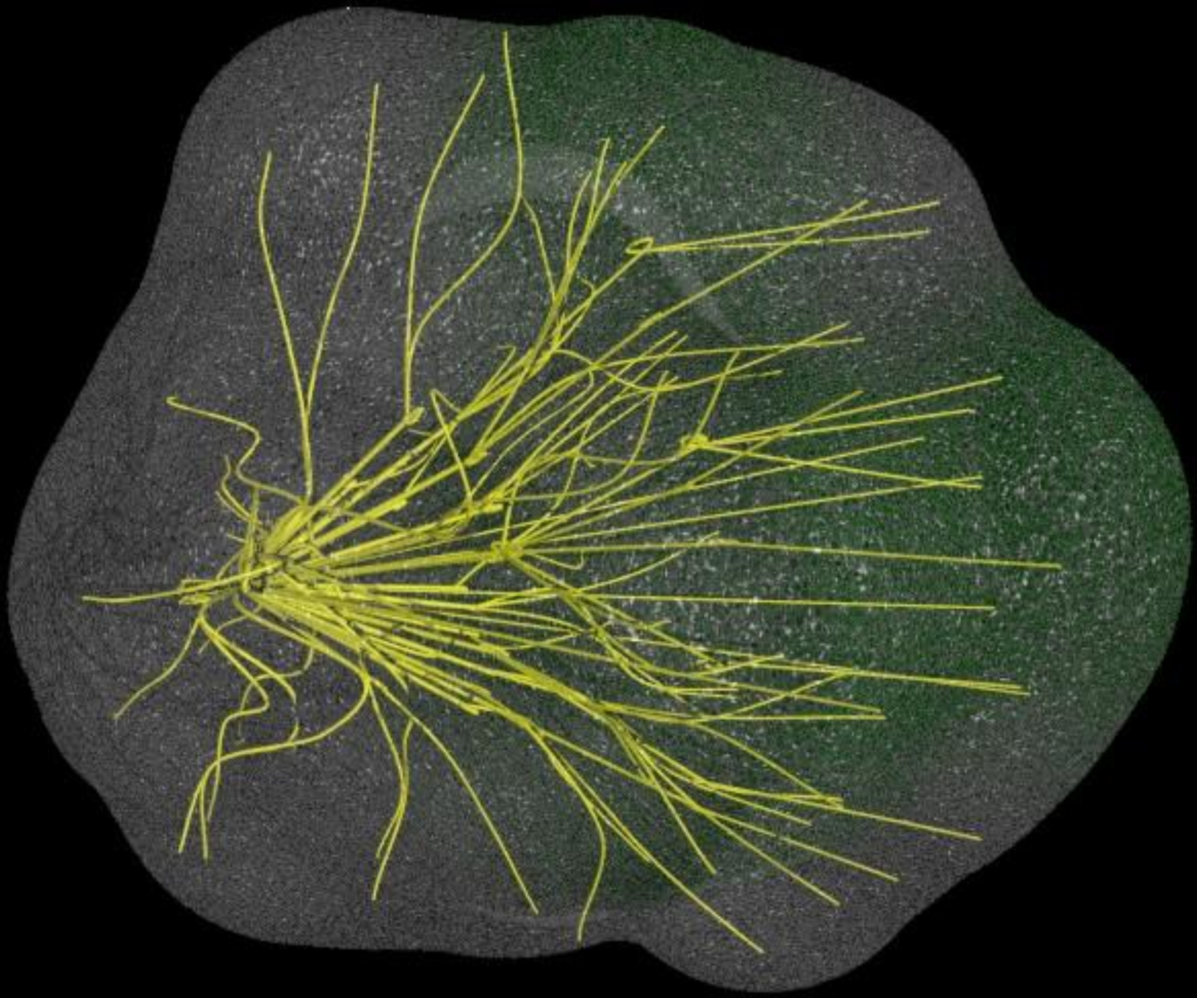
Fungi and some fungus-like bacteria lead a completely different life style. They are producing extensive hyphal networks.



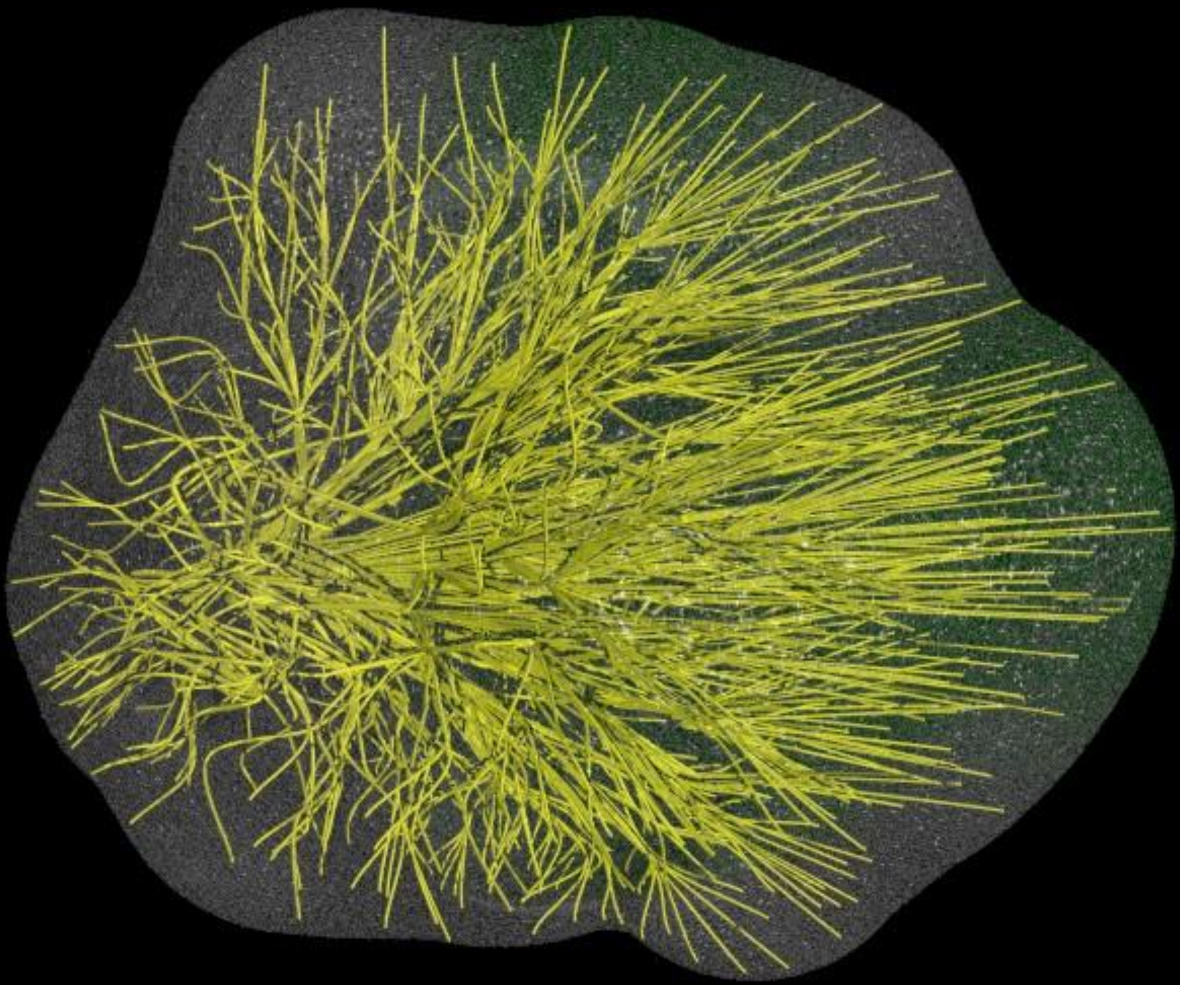
In contrast to bacteria, these hypha are able to grow <u>inside</u> many substrates.

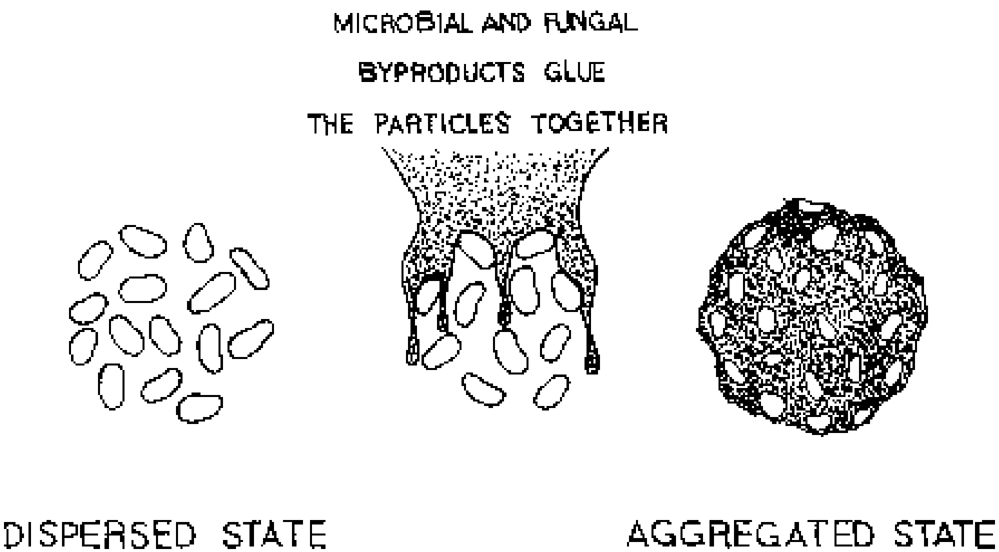


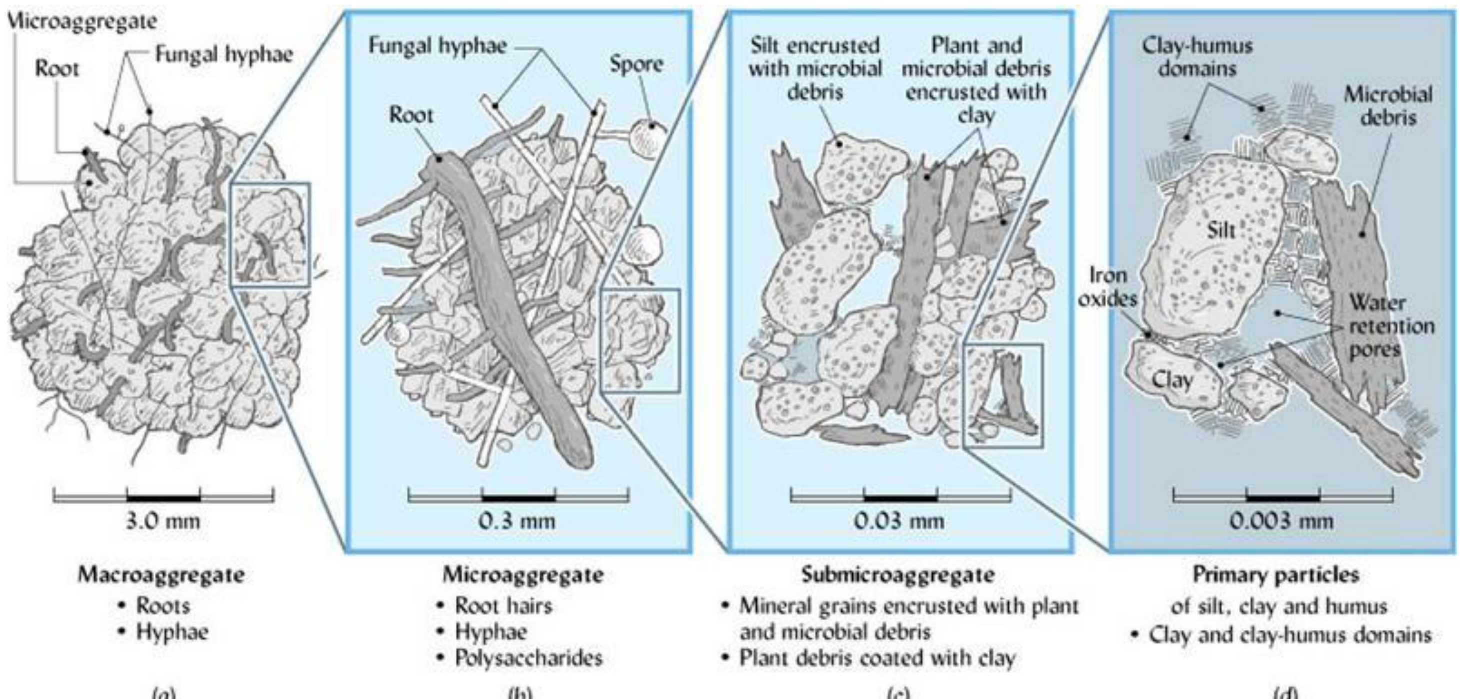
Since the hyphae can transport mineral nutrients, growth is not depending on local concentrations of such nutrients.



This way, fungi are able to thoroughly colonize and exploit a given organismic remnant.




MICROBIAL AND FUNGAL
BYPRODUCTS GLUE
THE PARTICLES TOGETHER
DISPERSED STATE
AGGREGATED STATE


Microaggregate
Root
Fungal hyphae
Spore
Silt encrusted with microbial debris
Plant and microbial debris encrusted with clay
Clay-humus domains
Microbial debris
Silt
Iron oxides
Water retention pores
Clay
3.0 mm
0.3 mm
0.03 mm
0.003 mm
Macroaggregate
• Roots
• Hyphae
Microaggregate
• Root hairs
• Hyphae
• Polysaccharides
Submicroaggregate
• Mineral grains encrusted with plant and microbial debris
• Plant debris coated with clay
Primary particles
of silt, clay and humus
• Clay and clay-humus domains
(a)
(b)
(c)
(d)

In optimal laboratory conditions, individuals can multiply extremely fast, increasing their biomass in short periods of time (in the order of days). However, in nature, the **turnover time of microbial biomass** generally varies between 6 and 18 months, that is 1,000 to 10,000 times slower than under laboratory conditions.

This indicates that in nature, micro-organisms are inactive most of the time. This inactivity may be due to **starvation**, resulting from their inability to move towards new substrates once their immediate surroundings are exhausted.

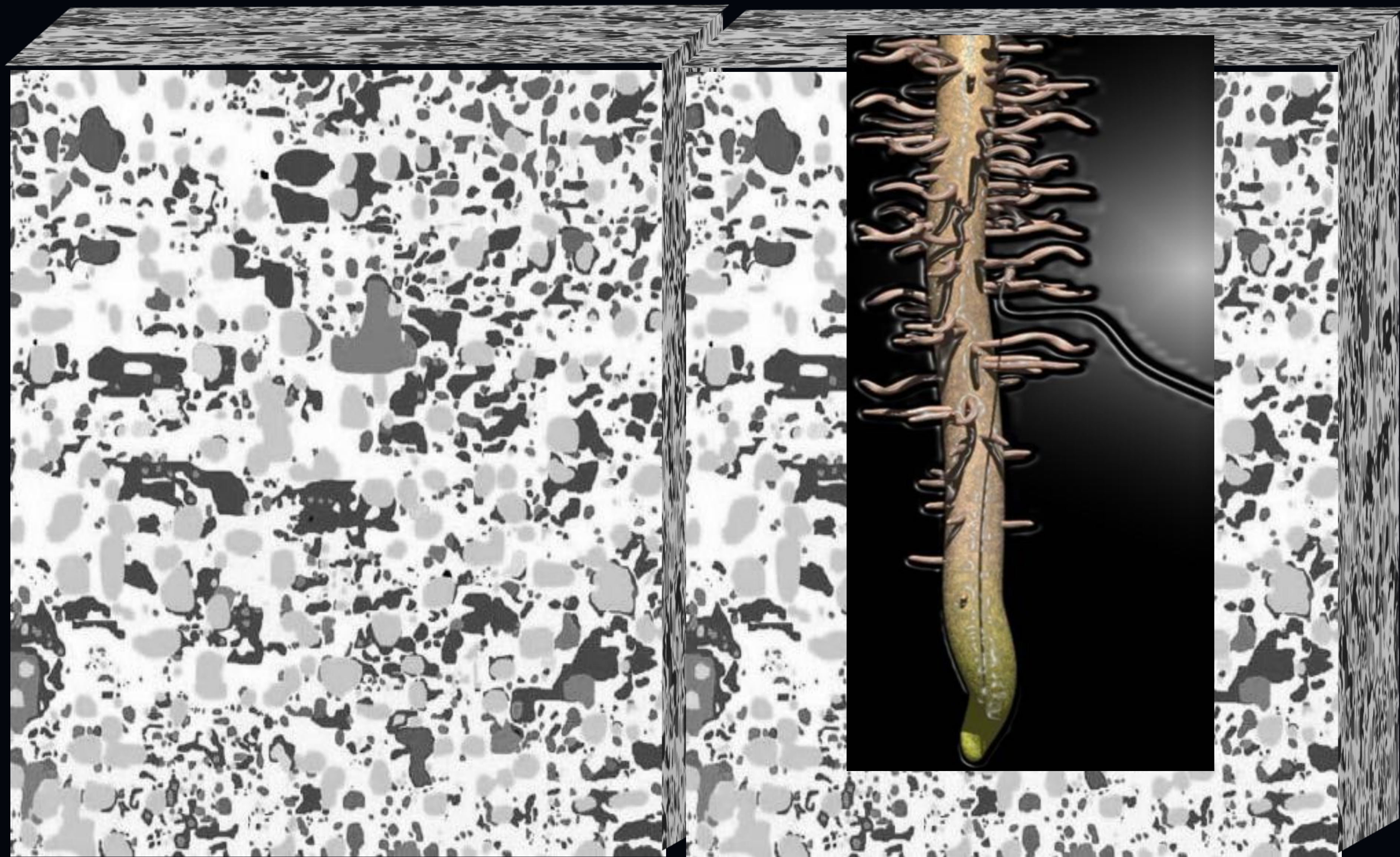

PLEASE
DO NOT
DISTURBE
WE ARE
STARVING

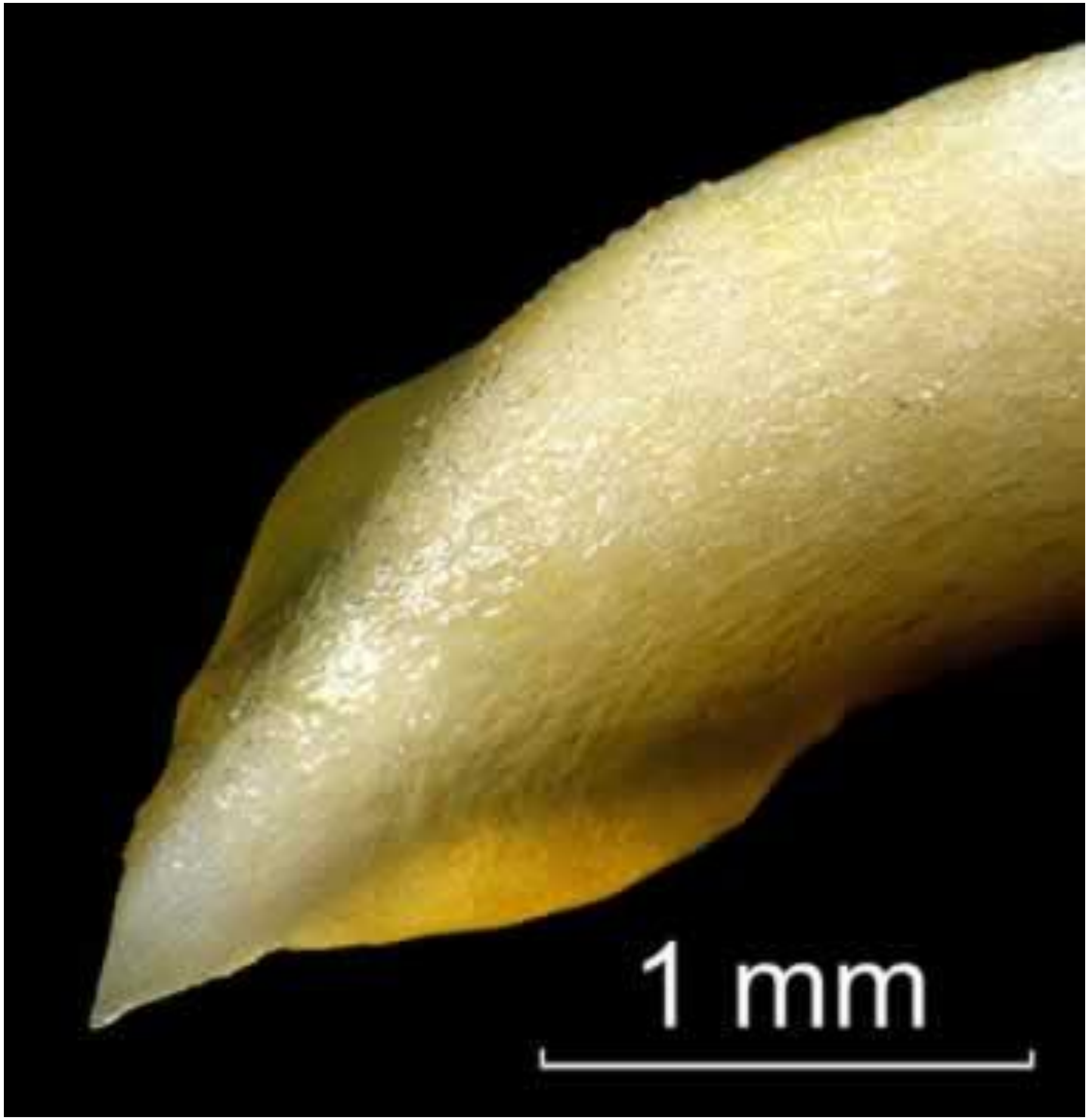
The apparent contradiction between laboratory and field observations has been named the ‘**Sleeping Beauty paradox**’ (Lavelle, Lattaud et al. 1995).

The ‘**Prince Charming**’ of the story is any macro-organism, including plant roots, or physical process that may bring microorganisms in contact with new substrates to decompose, thereby activating them.

Importantly, earthworms provide the suitable temperature, moisture and organic resources within their guts for microbes to be activated (Brown, Barois et al. 2000).

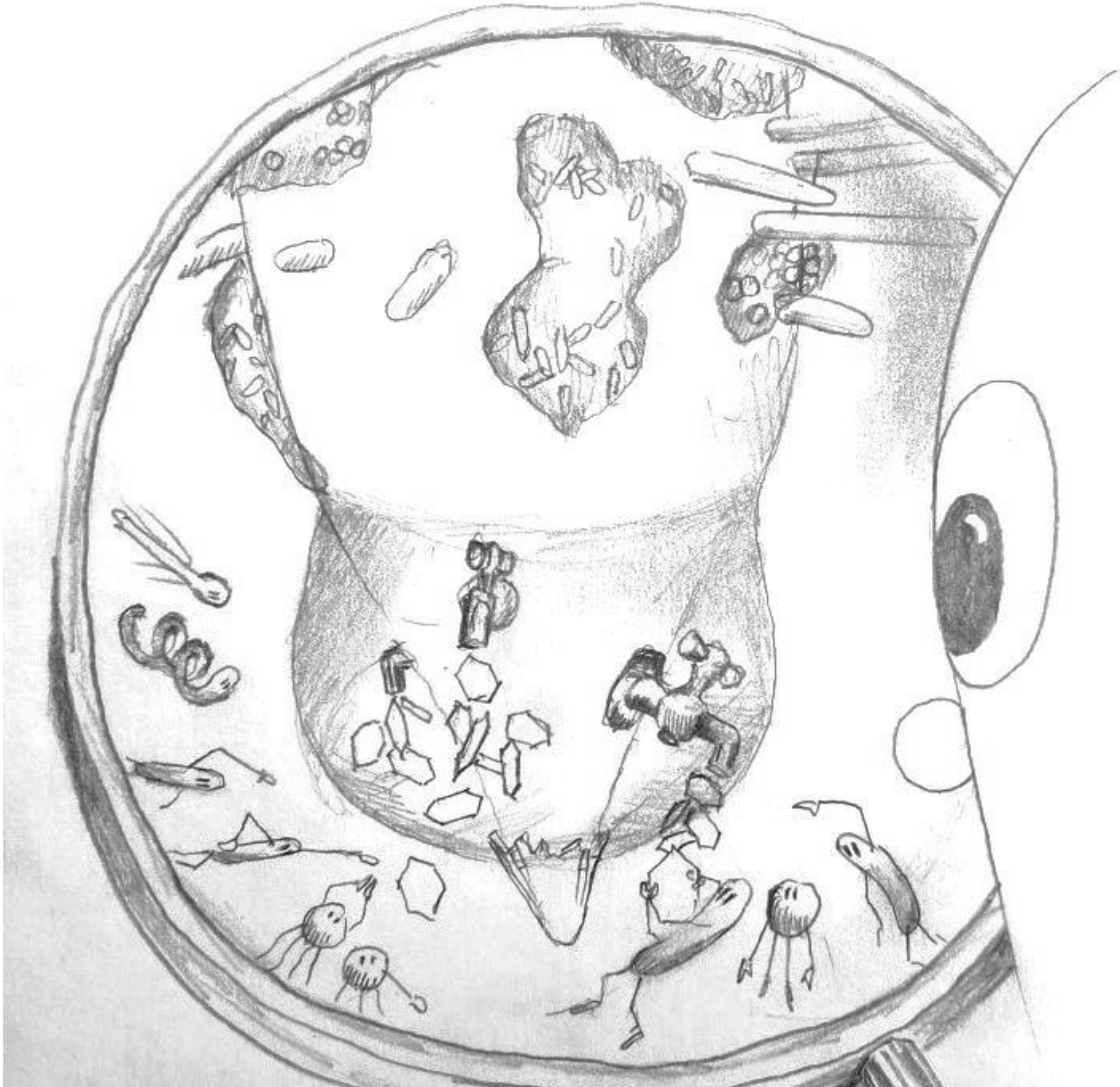
… 'Sleeping Beauty paradox' ….

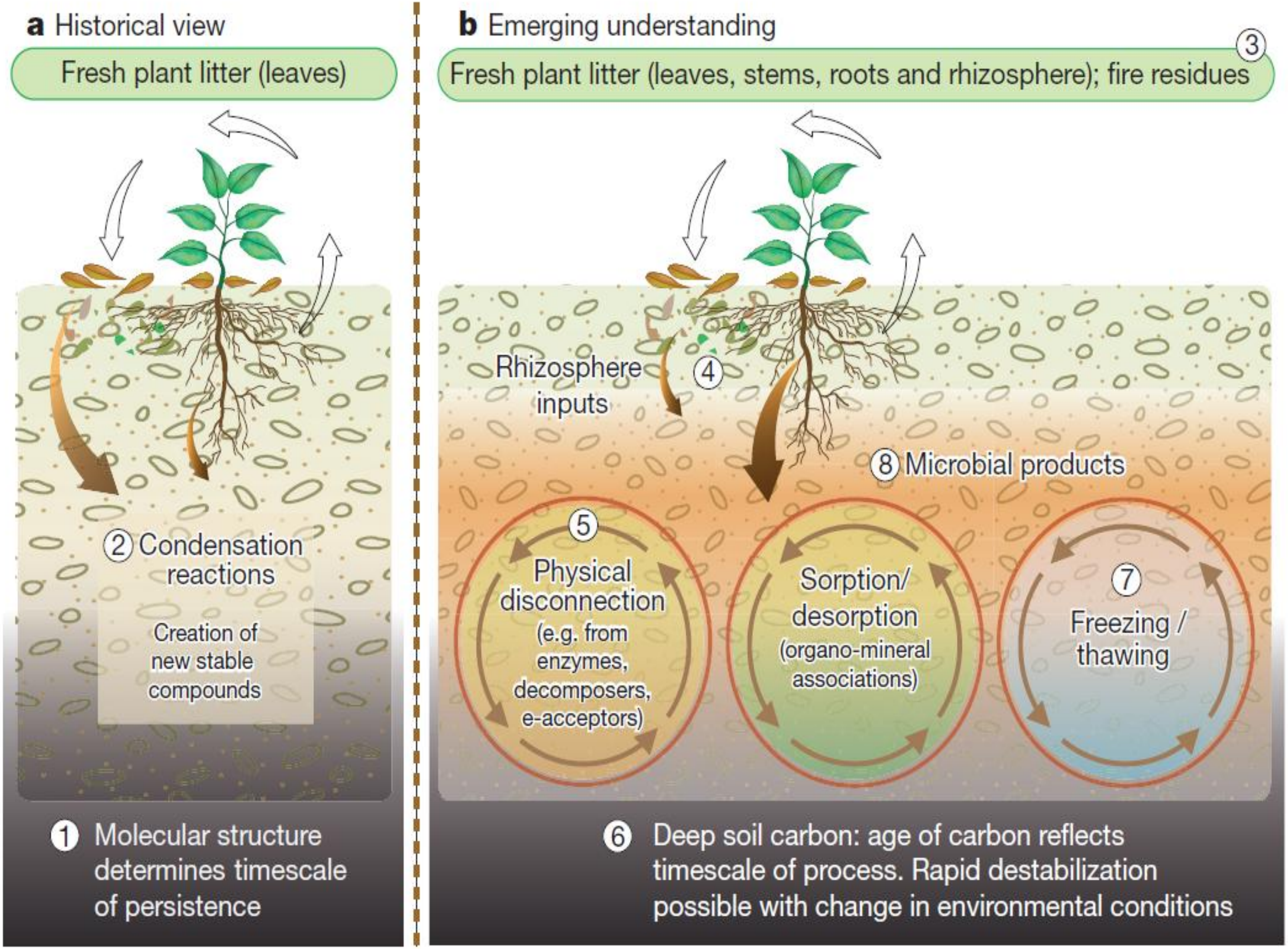


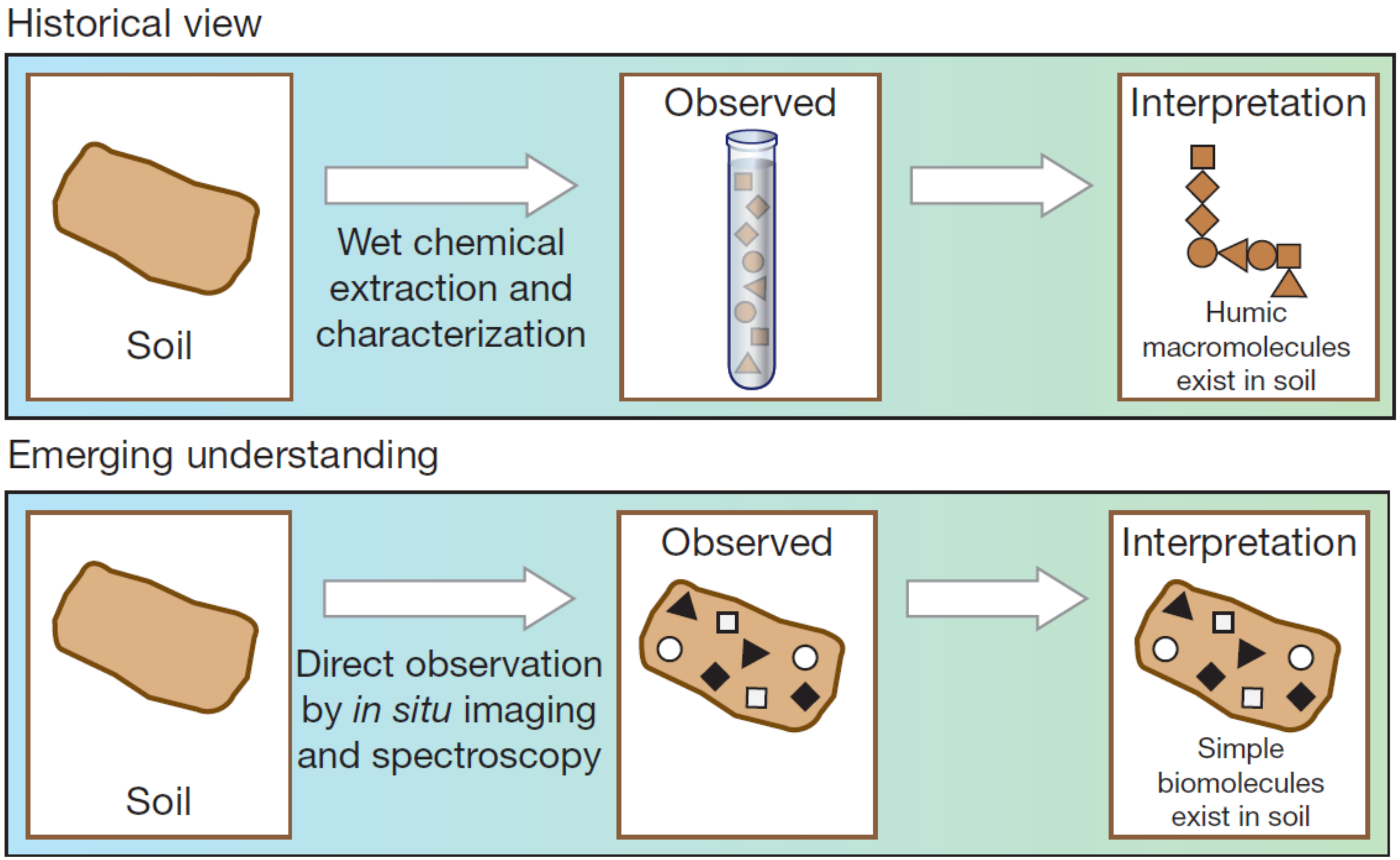


Micrograph of root cap with mucilage produced by the plant (maiz)

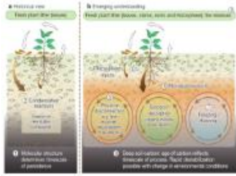
(Source: V. Sobolev, Agricultural Research Service, United States Department of Agriculture - ARS USDA)



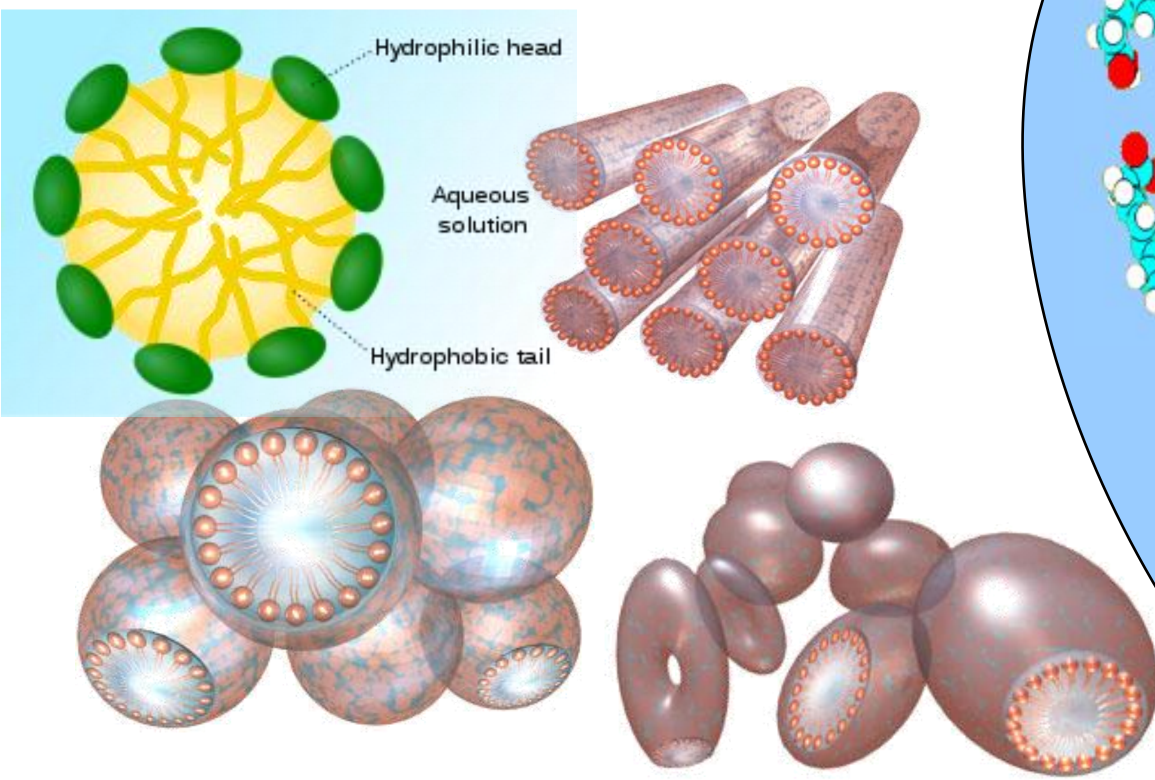

a Historical view
Fresh plant litter (leaves)
2 Condensation reactions
Creation of new stable compounds
1 Molecular structure determines timescale of persistence
b Emerging understanding
3
Fresh plant litter (leaves, stems, roots and rhizosphere); fire residues
Rhizosphere inputs
4
8 Microbial products
5
Physical disconnection (e.g. from enzymes, decomposers, e-acceptors)
Sorption/ desorption (organo-mineral associations)
7
Freezing / thawing
6 Deep soil carbon: age of carbon reflects timescale of process. Rapid destabilization possible with change in environmental conditions

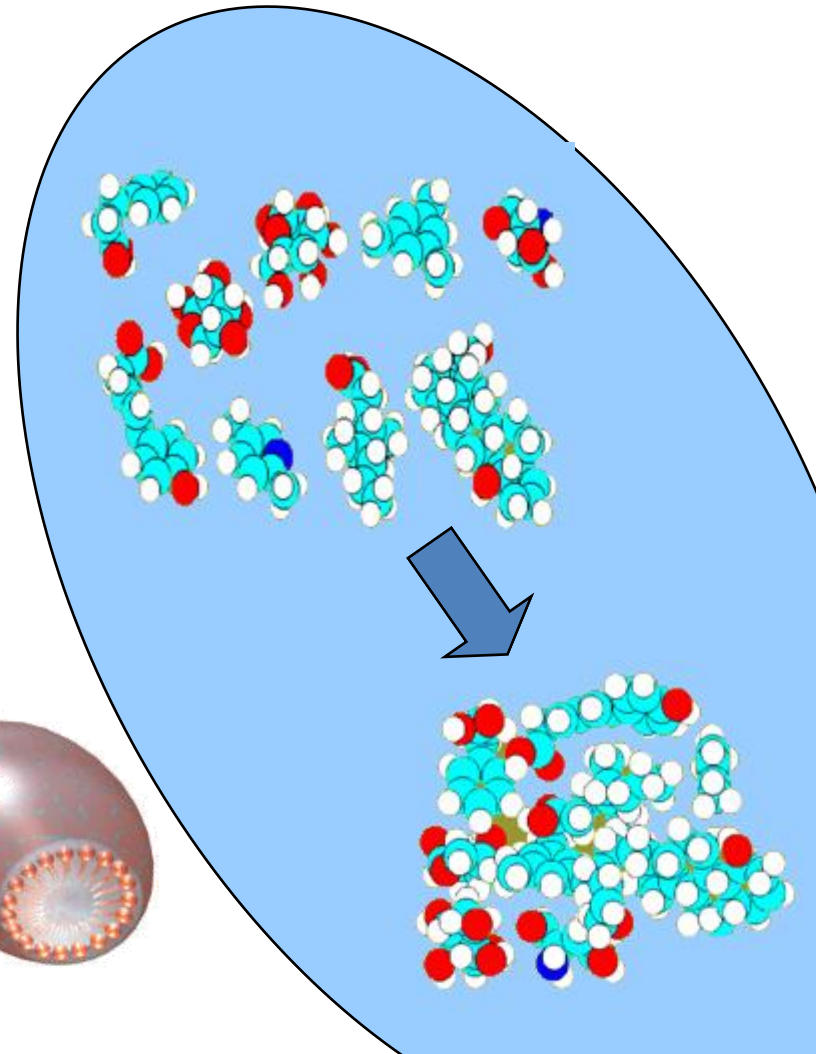


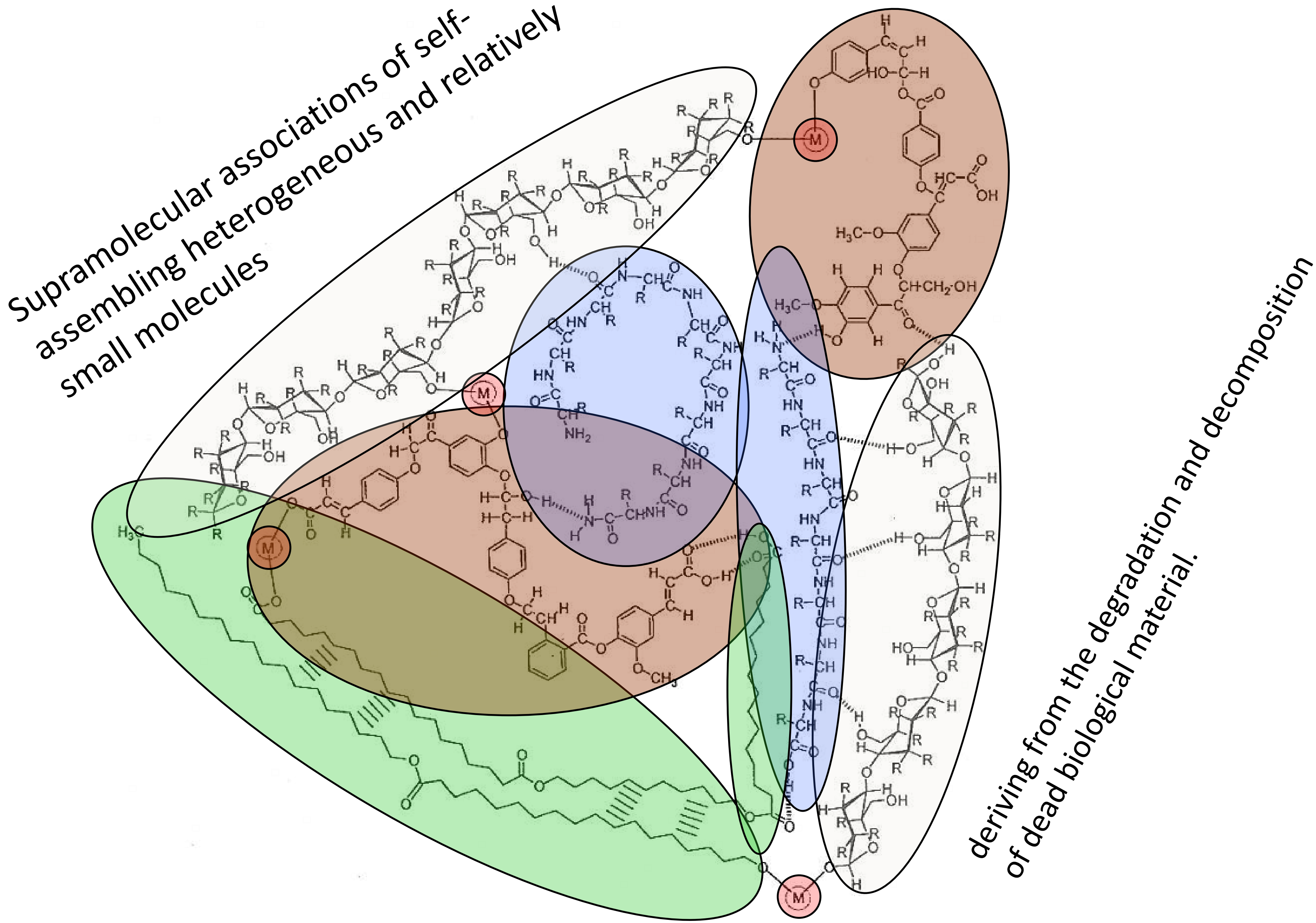
Direct high-resolution *in situ* observations with non-destructive techniques have been able to explain the functional group chemistry of the extracted humic substances as relatively simple biomolecules without the need to invoke the presence of unexplainable macromolecules.



A major aspect of the humic supramolecular conformation is that it is stabilized predominantly by weak dispersive forces instead of covalent linkages (Piccolo, 2001).

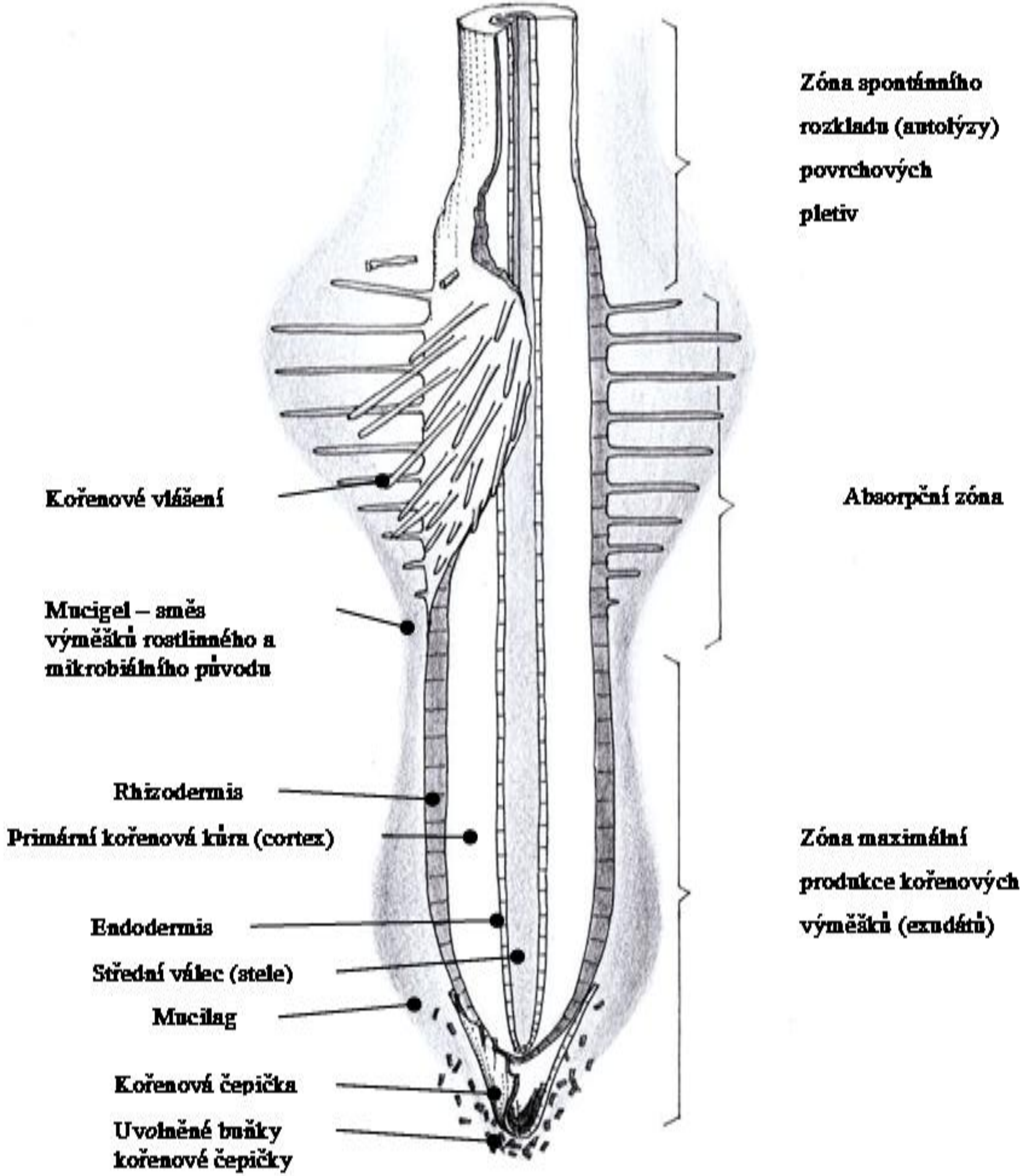





Supramolecular associations of self-assembling heterogeneous and relatively small molecules
deriving from the degradation and decomposition of dead biological material.

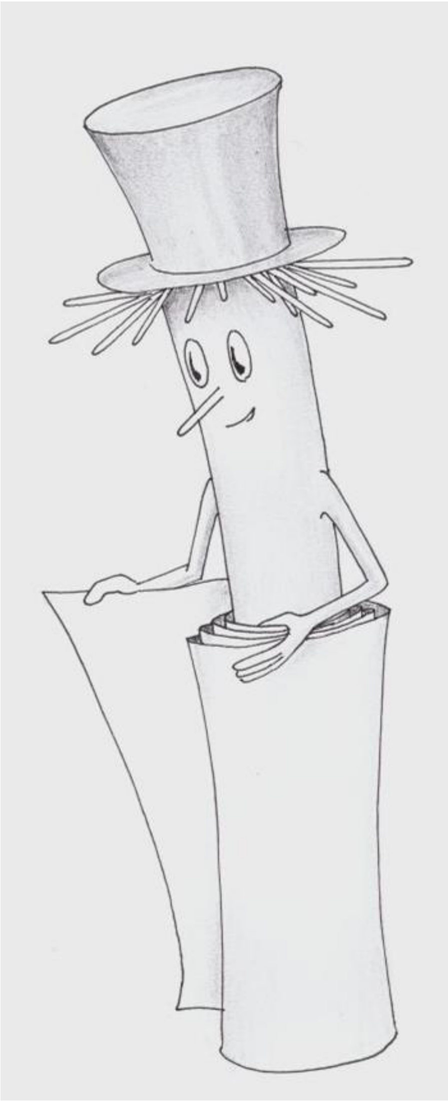
It appears, based on the emerging understanding, that part of SOM is a special kind of extracellular microbial reservoir of key biogenic nutrients (N, P, S, ...), well preserved against the spontaneous microbial activities („**Sleeping Beauty**“) without the additional source of carbohydrates but well prepared for explosive microbial activities after the stimulation with rhizodeposits.

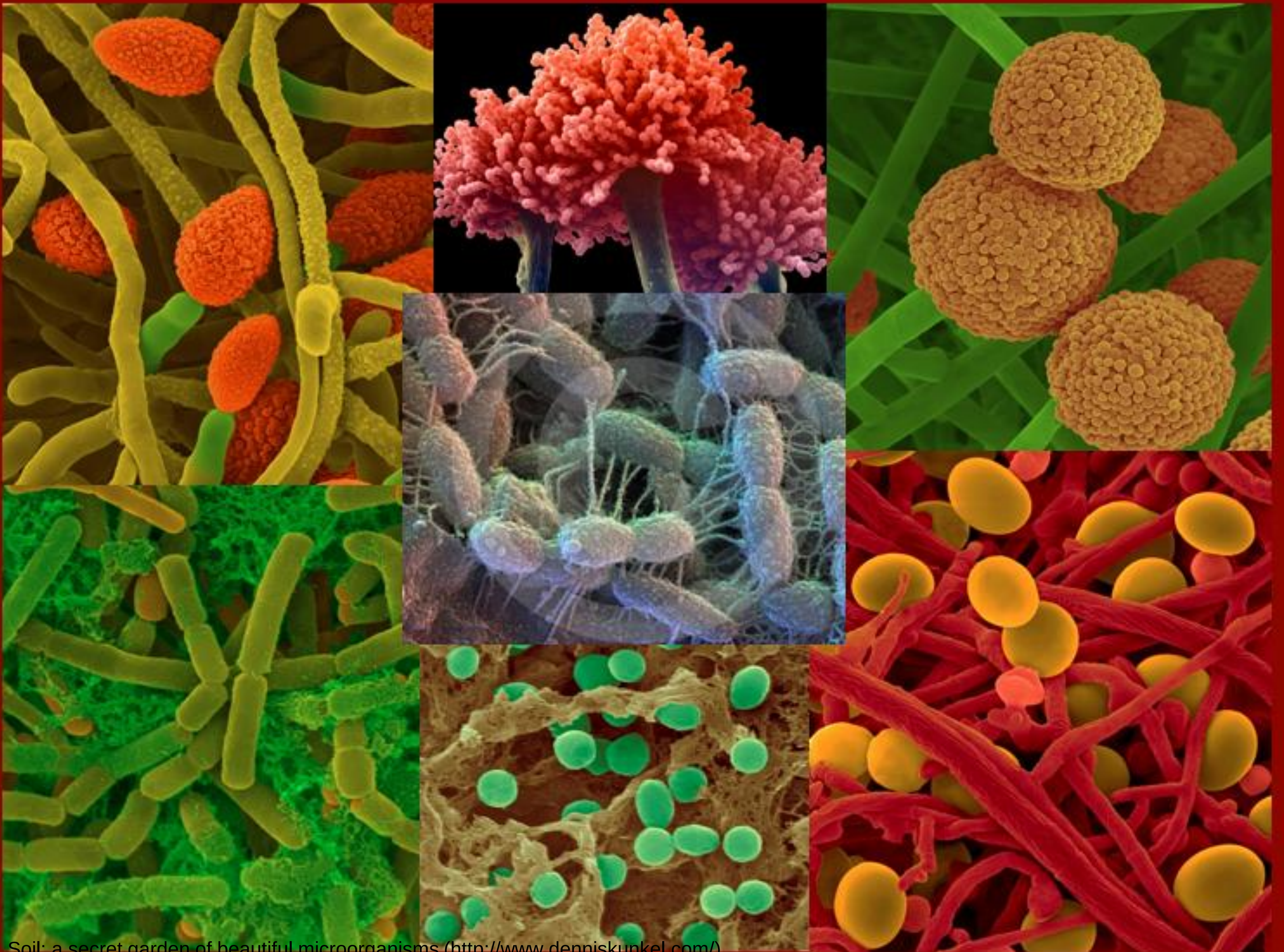
In other words, the major reservoir of soil nitrogen must be first activated by delivery of well accesive plant rhizodeposits and the rate of nitrogen availability will be directly proportional to the supply of plant carbohydrates.


Zóna spontánního
rozkladu (autolýzy)
povrchových
pletiv
Kořenové vlášení
Absorpční zóna
Mucigel – směs
výměšků rostlinného a
mikrobiálního původu
Rhizodermis
Primární kořenová kůra (cortex)
Zóna maximální
produkce kořenových
výměšků (exudátů)
Endodermis
Středaní válec (stele)
Mucilag
Kořenová čepička
Uvolněné buňky
kořenové čepičky

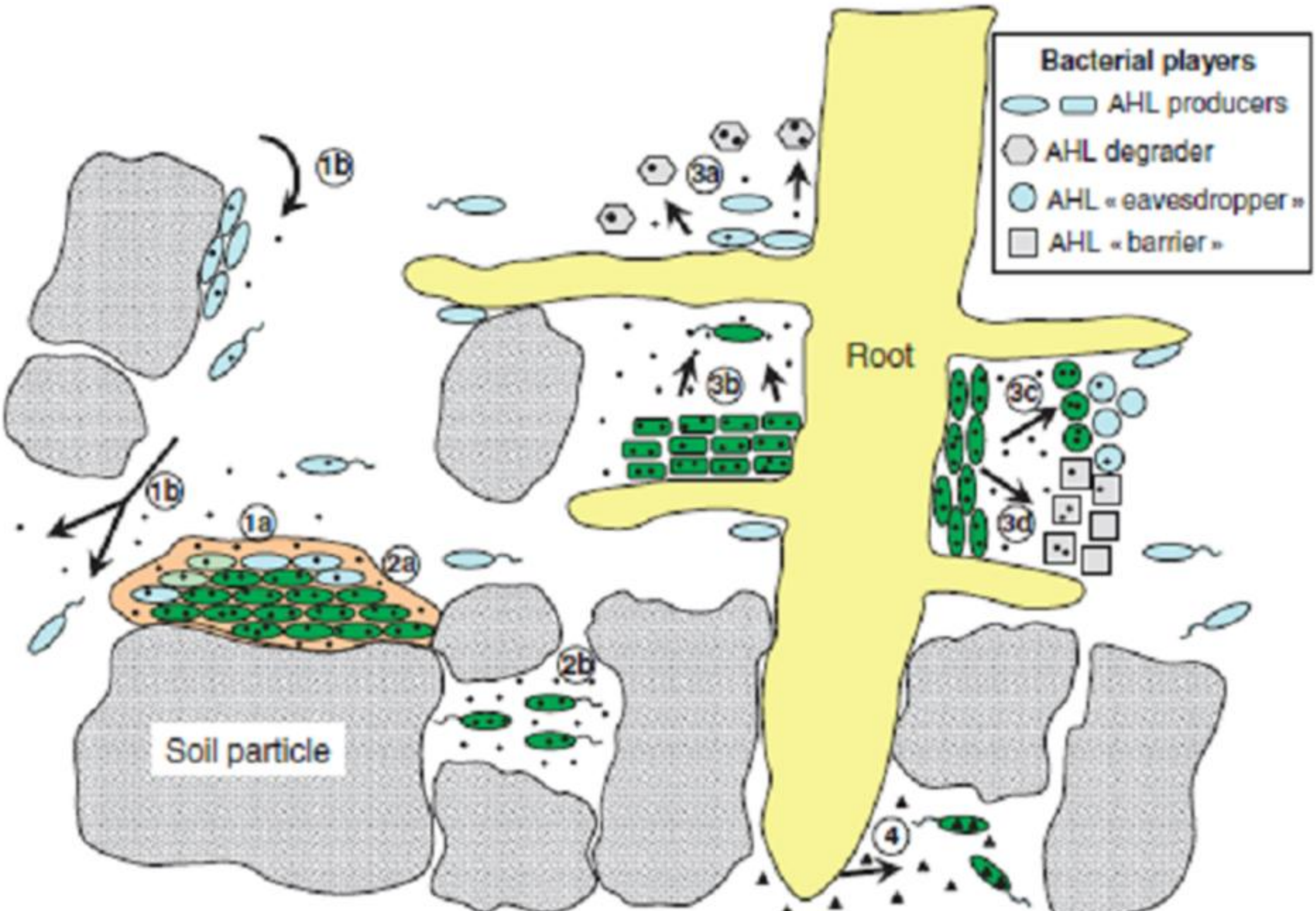
The pictures show a plant roots "dressed up" to the active surface represented by exchangeable surface structures (plasma membranes) of microorganisms, which are proliferated in the vicinity due to the production of root exudates.

Otherwise unavailable biogenic nutrients are released from SOM by extracellular enzymes produced by microorganisms as a result of an excess of carbonaceous compounds and the lack of these nutrients. From this phenomenon is ultimately benefiting the plant in proportion to their carbonaceous “investment”.





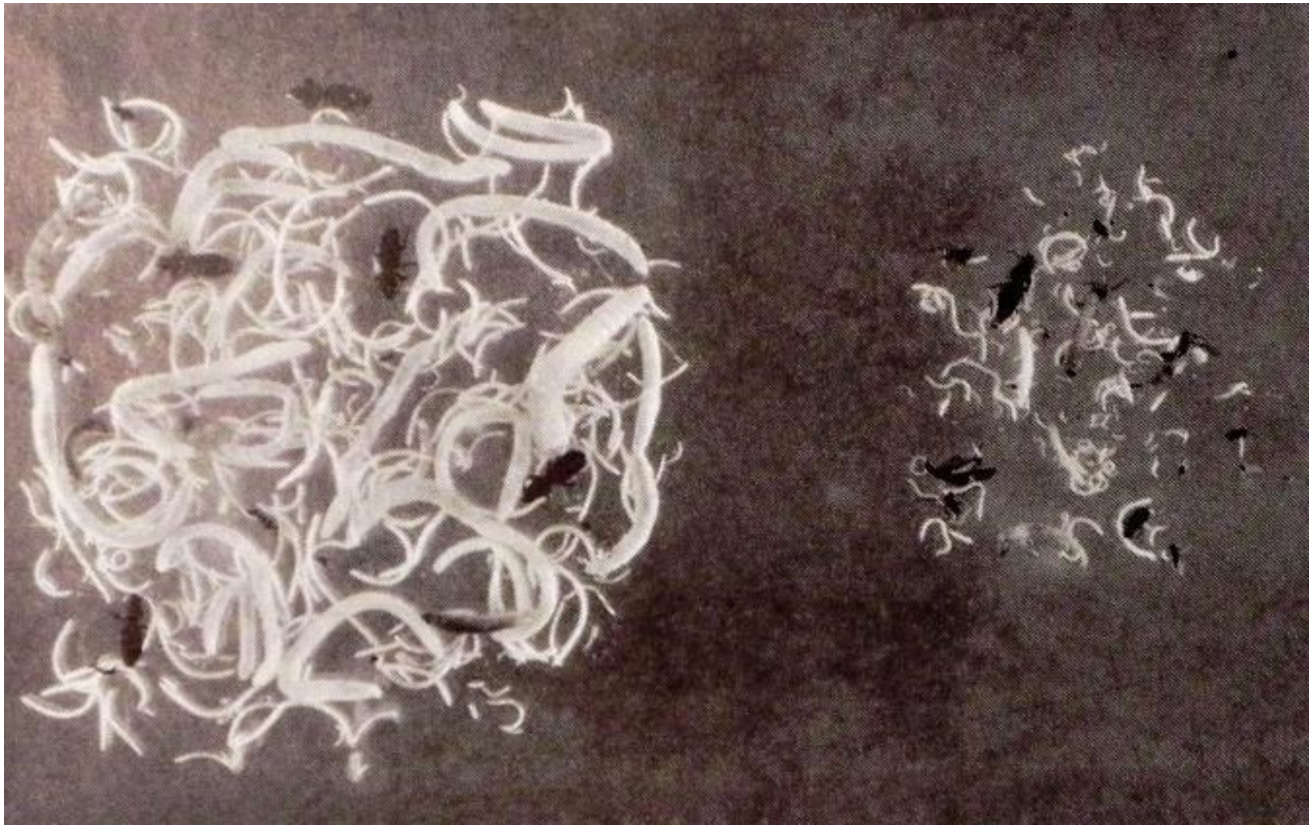
Soil: a secret garden of beautiful microorganisms (http://www.denniskunkel.com/)



Bacterial players
AHL producers
AHL degrader
AHL « eavesdropper »
AHL « barrier »
Root
Soil particle
1a
1b
1b
2a
2b
3a
3b
3c
3d
4

Bioturbation, microbiocomposting …

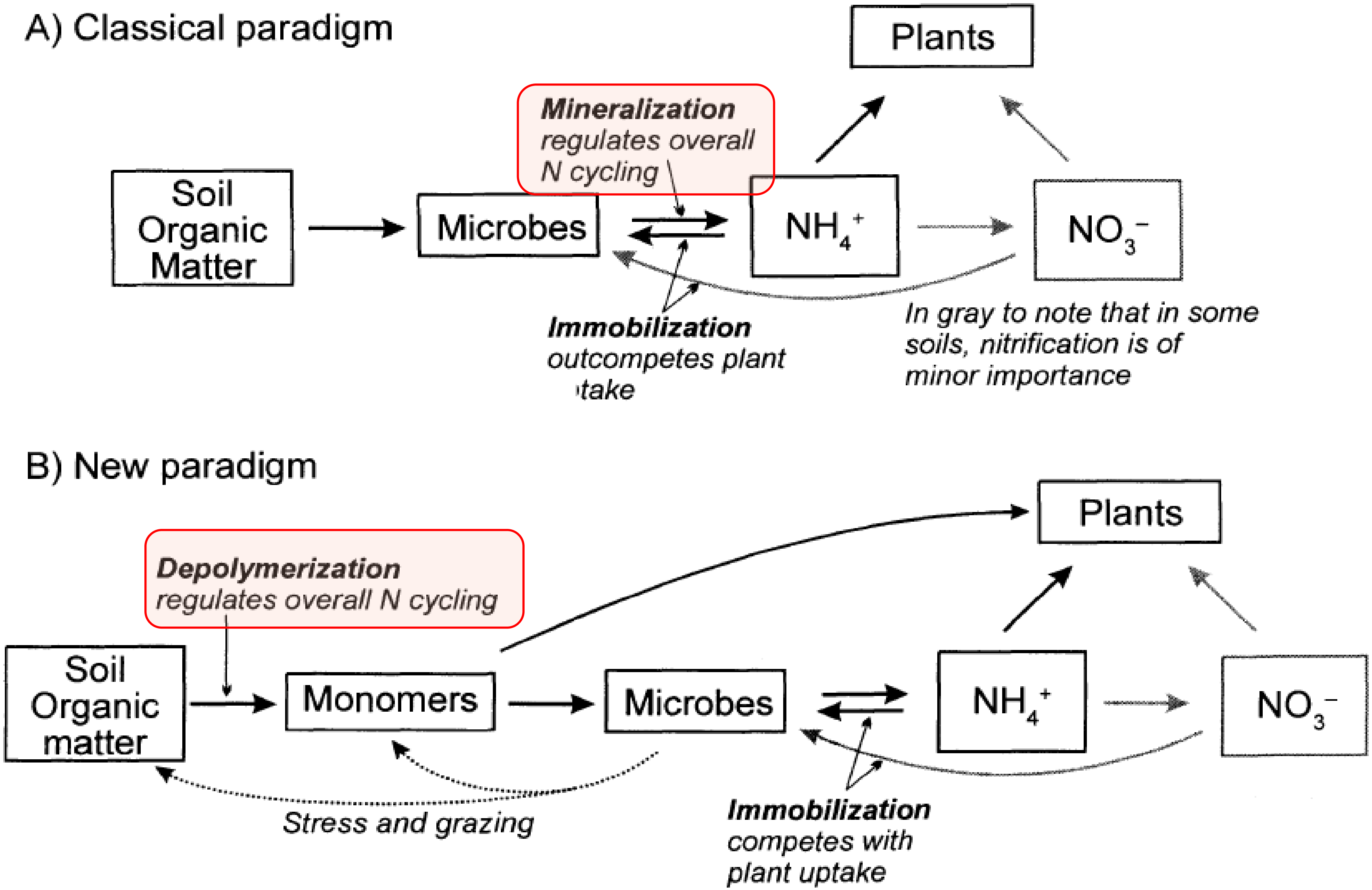
Soil, how are you …… with human?



biological agriculture

conventional agriculture

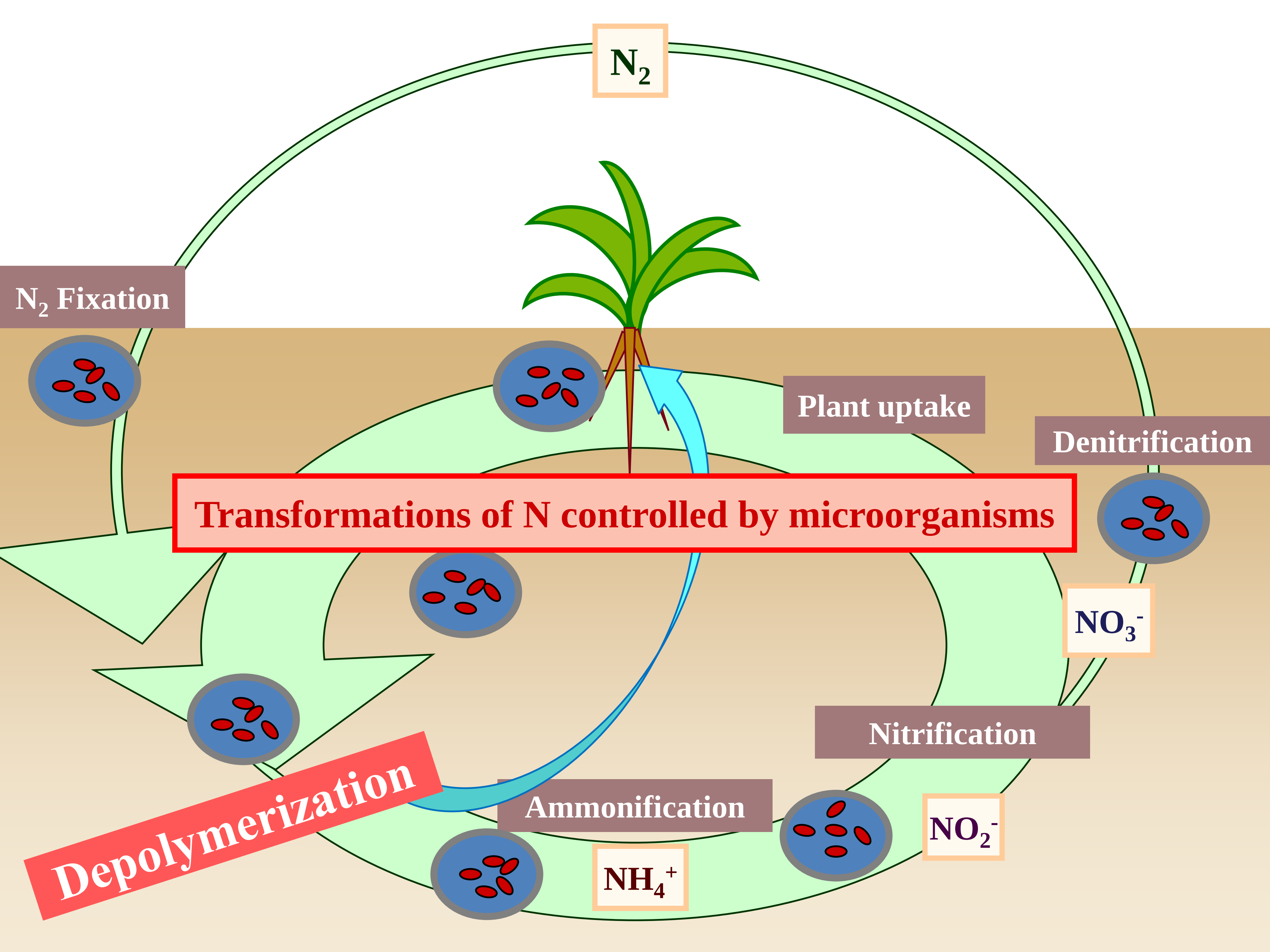
Comparison of two extractions of the soil fauna: similar soils (CALCISOLS), similar altitudes (500 m), similar climates (oceanic temperature of then Switzerland Plateau), identical crop (wheat). At the left, under conditions of **biological agriculture**; at right, under conditions of **conventional agriculture**. Life in the soil ….soils are poorly developed and have a limited capacity to store N inputs /Gobat et al., 2003: The Living Soil/



(Schimel et Bennett, 2004)

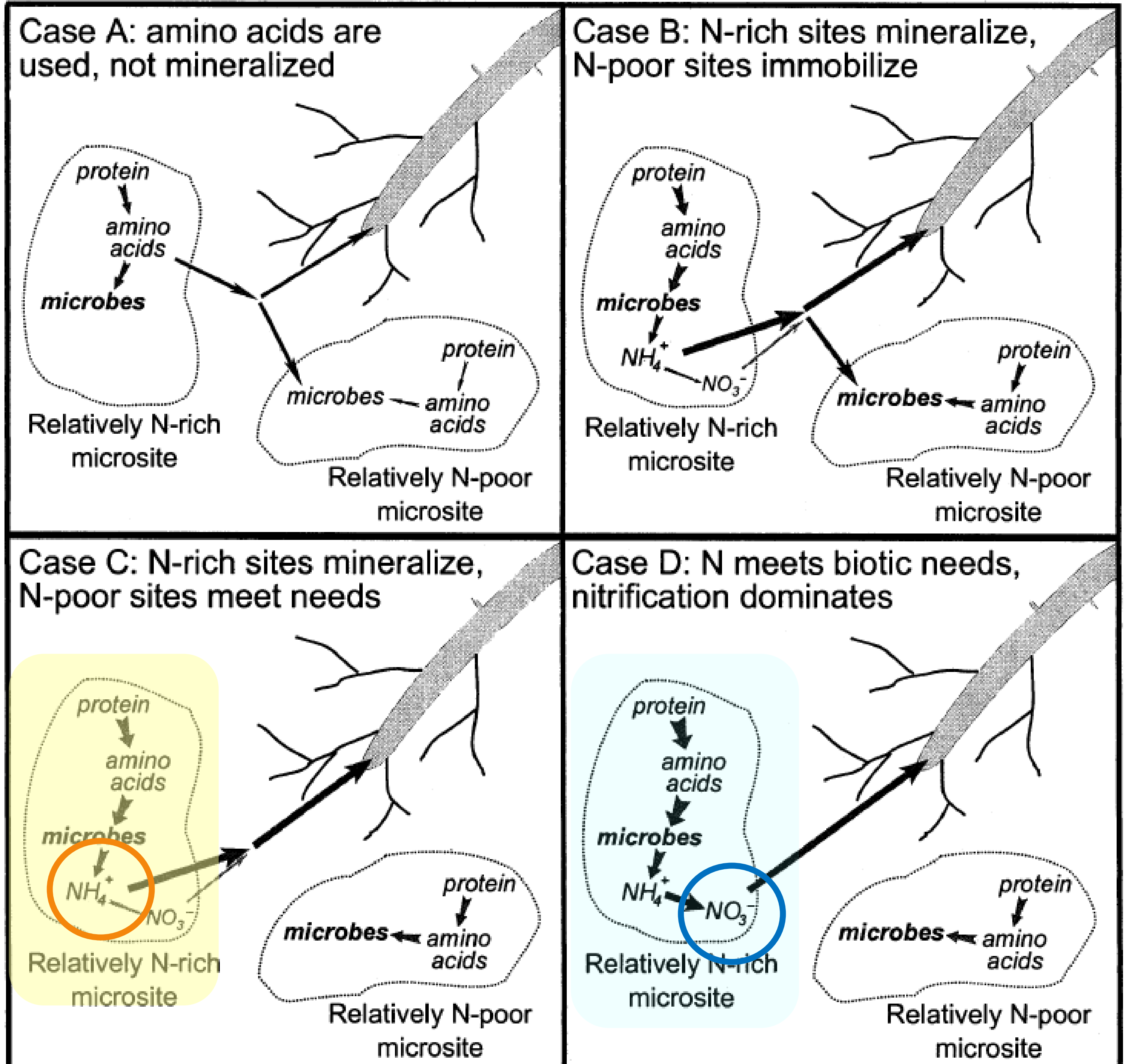
The changing paradigm of the soil N cycle.

N cycling is now seen as being driven by the depolymerization of N-containing polymers by microbial extracellular enzymes.

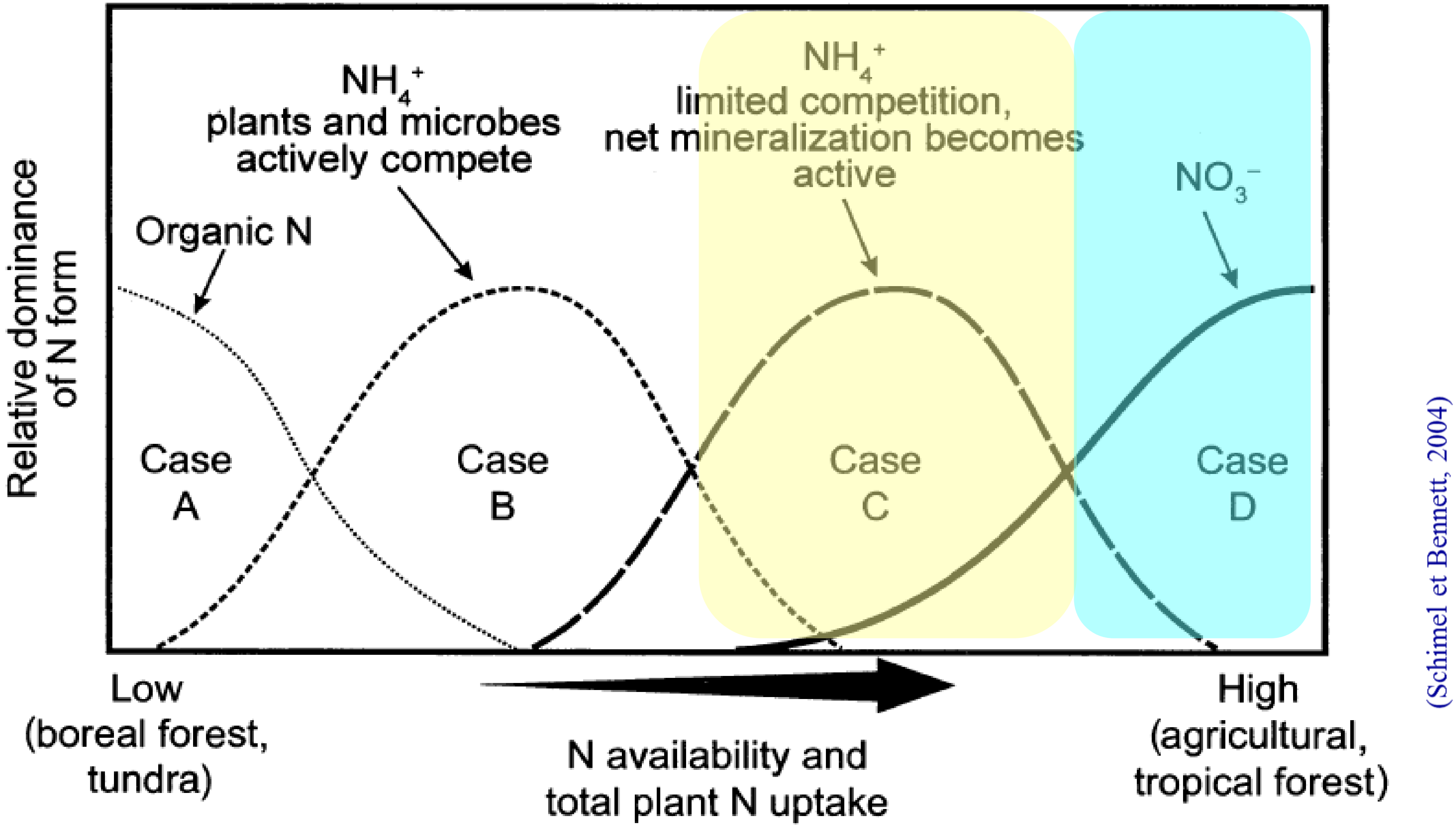


N2
N2 Fixation
Plant uptake
Denitrification
Transformations of N controlled by microorganisms
NO3-
Nitrification
NO2-
Ammonification
NH4+
Depolymerization

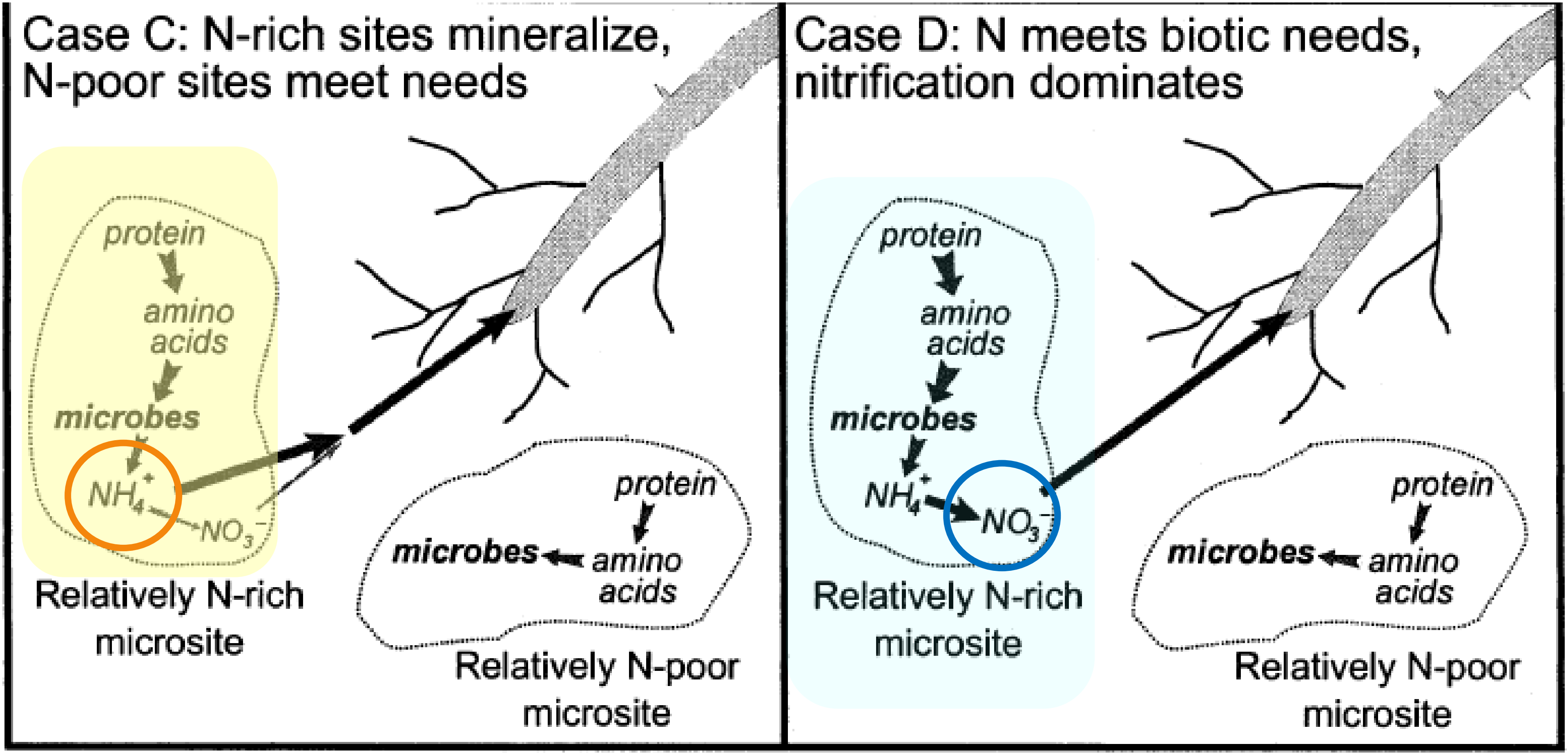
The diagrams specify that the polymers are protein, but only as a representative organic N-containing polymer.



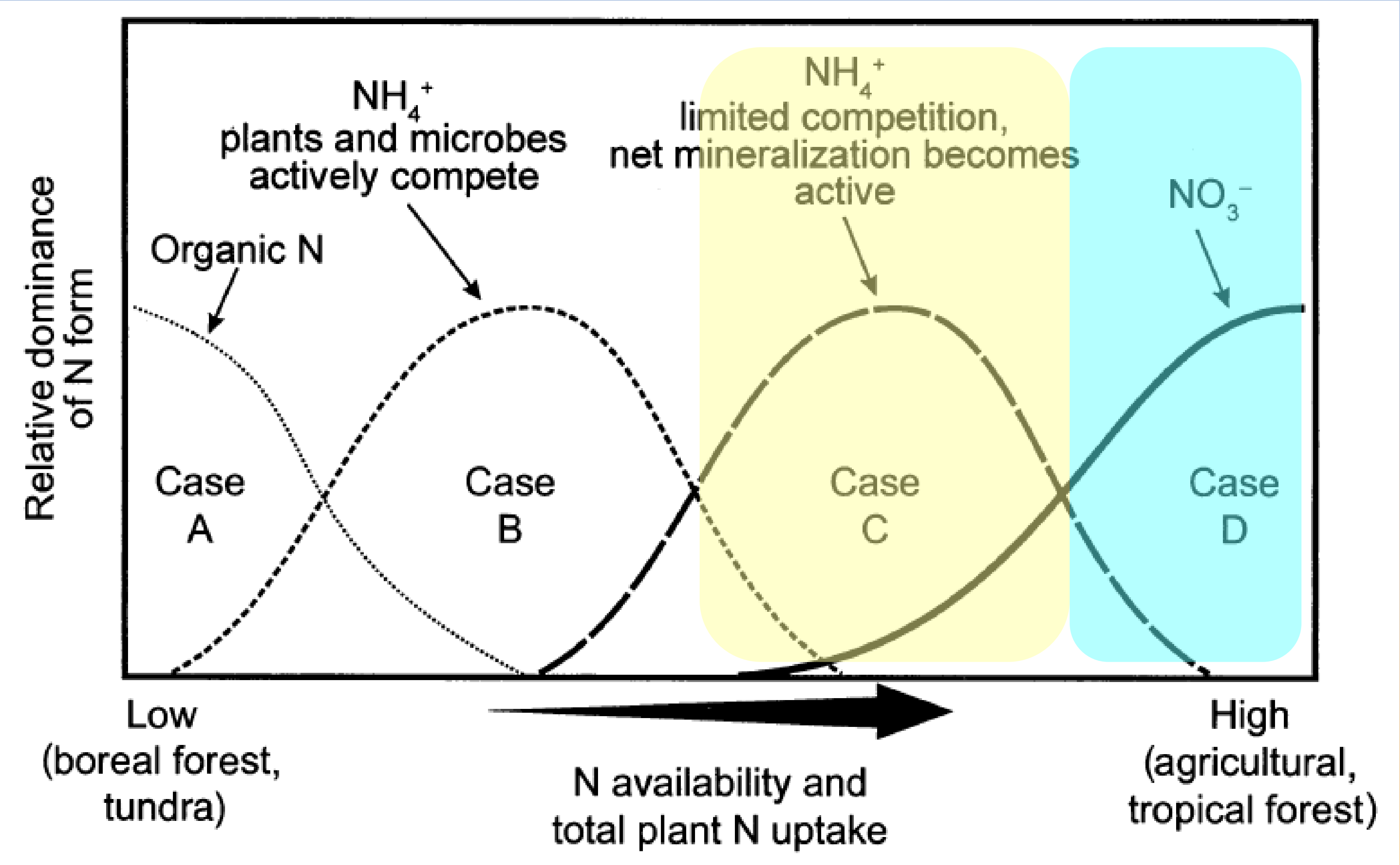
(Schimel et Bennett, 2004)



The shifting dominance of N forms along a gradient of N availability and the soil processes that regulate N availability to plants under different N-availability regimes. Total N availability and plant uptake both increase along the hypothetical gradient.



If we (farmers) add some more mineral nitrogen, then the aboveground plant production increased, but the plants do not need to release their carbohydrates into the soil environment. Therefore the process of carbon sequestration in soil will be discriminated.

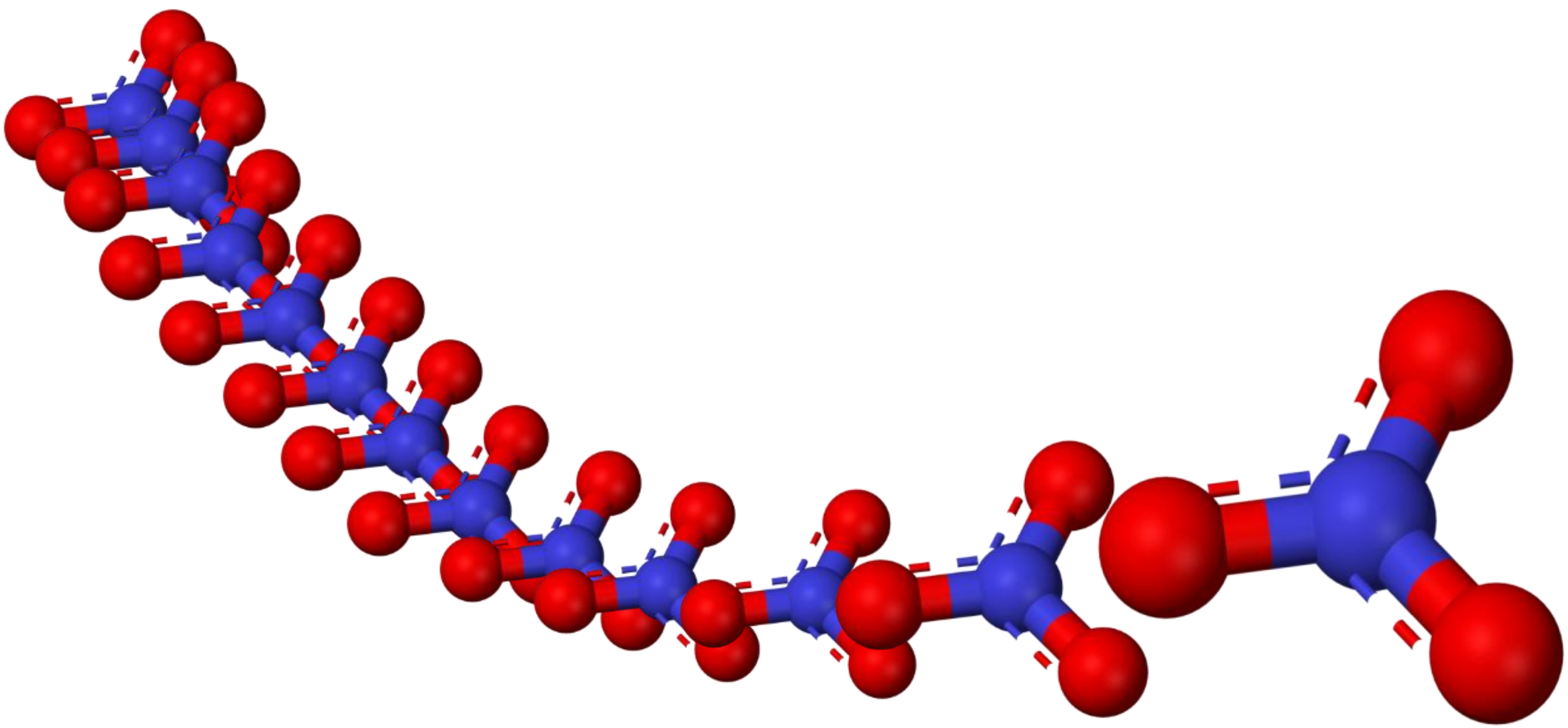


(Schimel et Bennett, 2004)

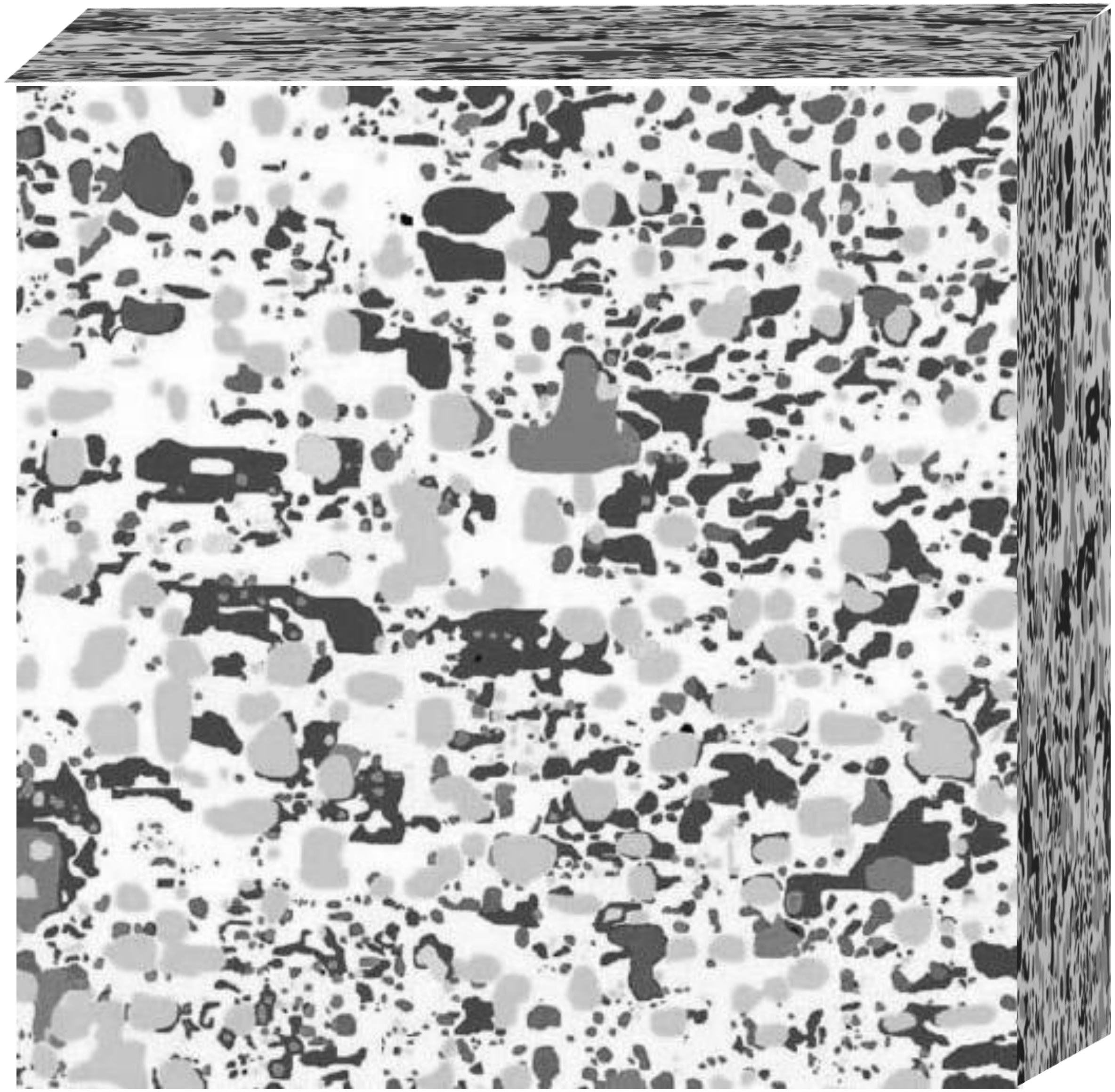
If we were able to capture an excess of NH_4^+ and NO_3^- ions from soil solution, then we will be able to assess at what stage is the current N-load of the ecosystem.

Nitrates, where are you coming from and where are you going?

Nitrate is a critical signaling molecule in regulating plant growth, little is know about plant nitrate signaling at molecular level and even less about the role of nitrate signaling for interactions between key players in soils.



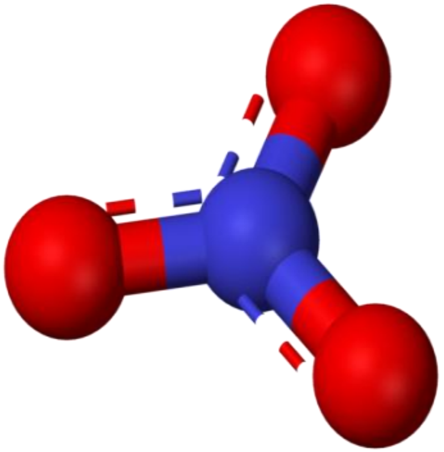
In the natural ecosystems can nitrates as movable compounds balance nitrogen availability in heterogeneous soil environment



What kind of information constitutes the presence of nitrate-N in soils?

- for plants?
- for microbes?
- for ecosystem?

- prolonged oxidative conditions and lack of interest about ammonium-N from plants or microbes
- nitrogen saturation (oversaturation?)
- rainfall event and its consequences,
- ……



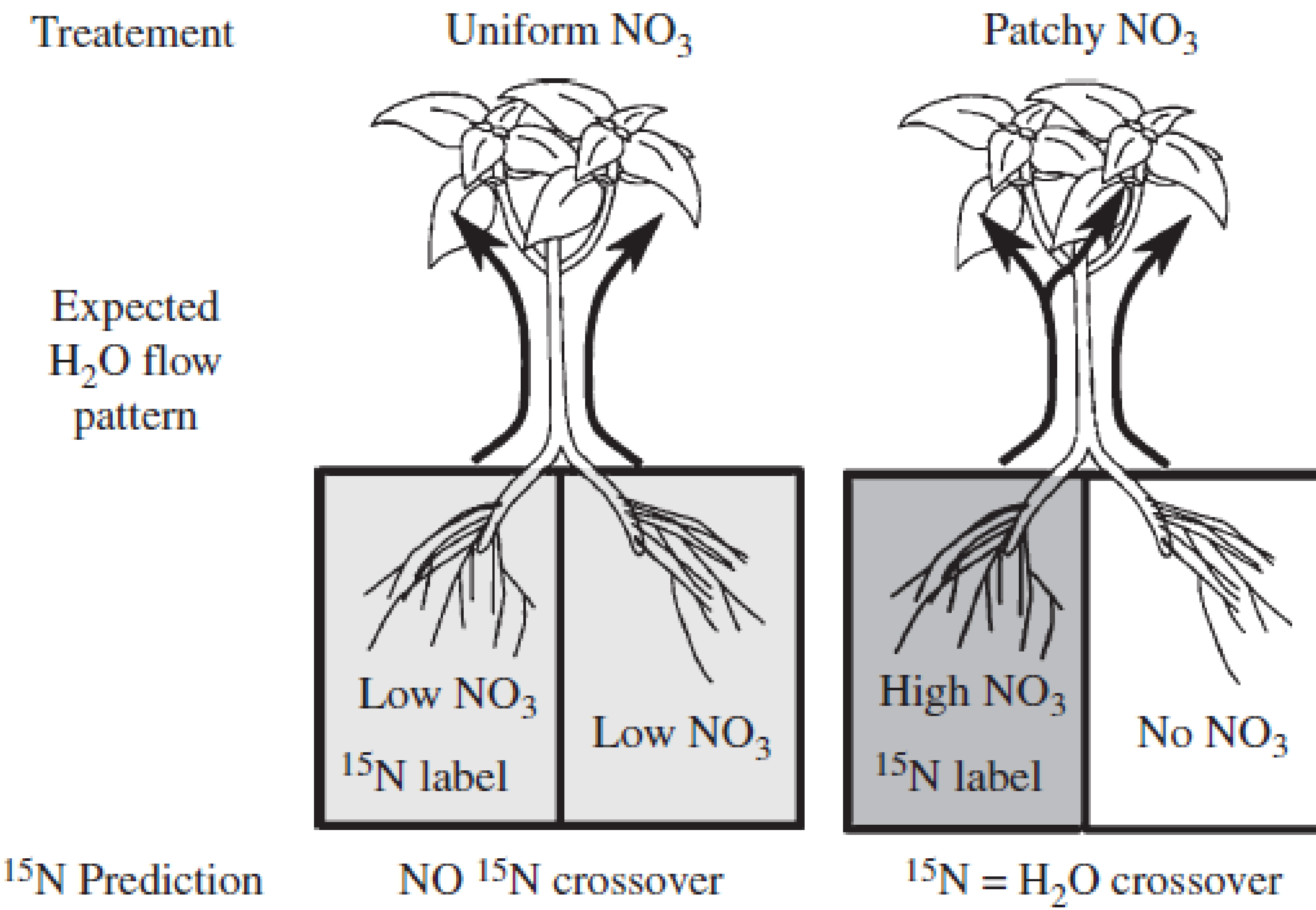
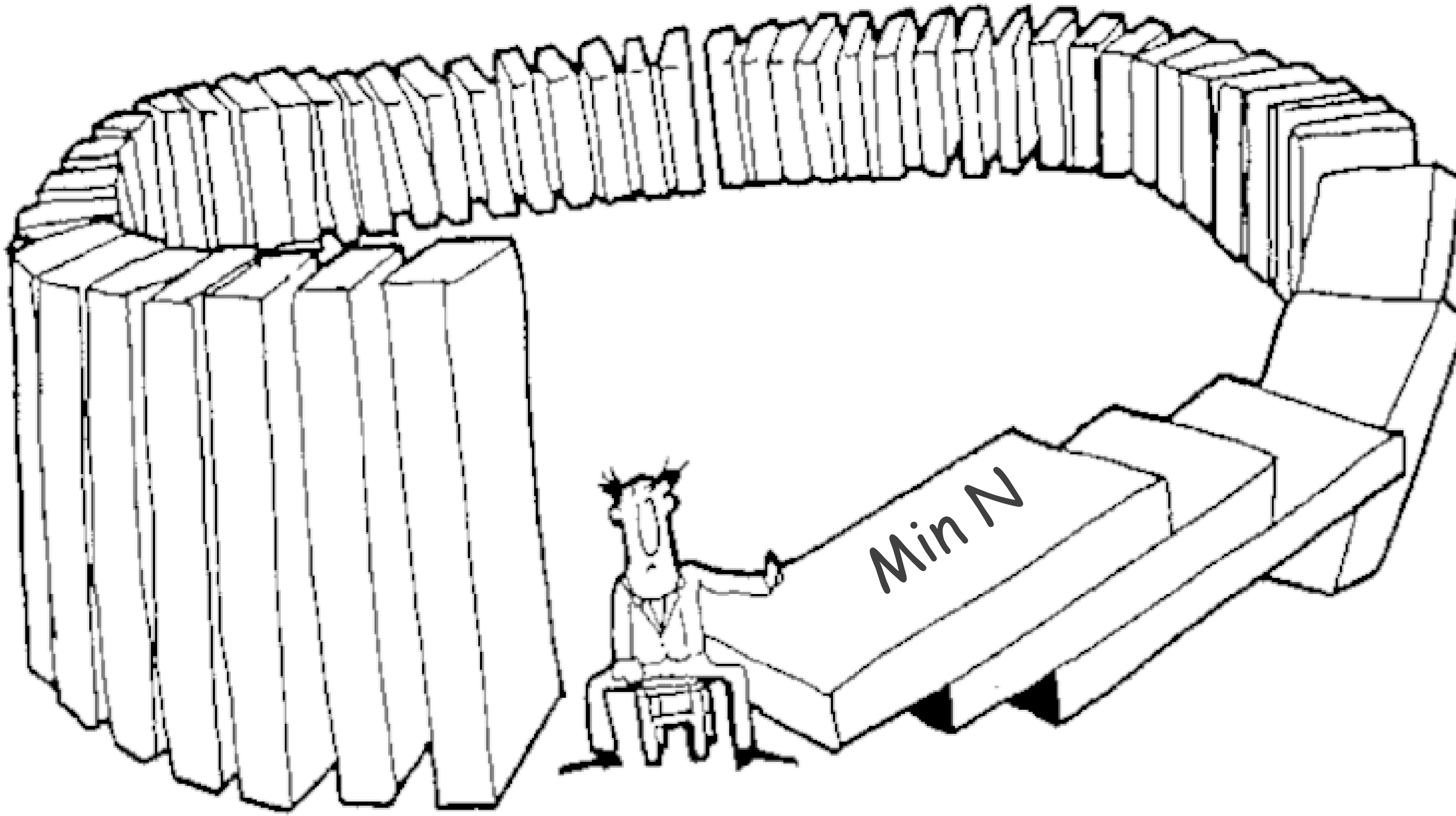
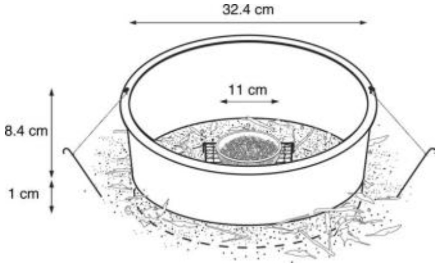


Diagram of qualitative predictions for how water and nutrient movement will be affected if roots in a nutrient patch have lower resistance than roots in the background nutrient environment
(Thorn et Orians, 2011).



In a complex system are the causes and consequences temporally and spatially separated but if farmers apply nitrates, they should take care of their fates ….

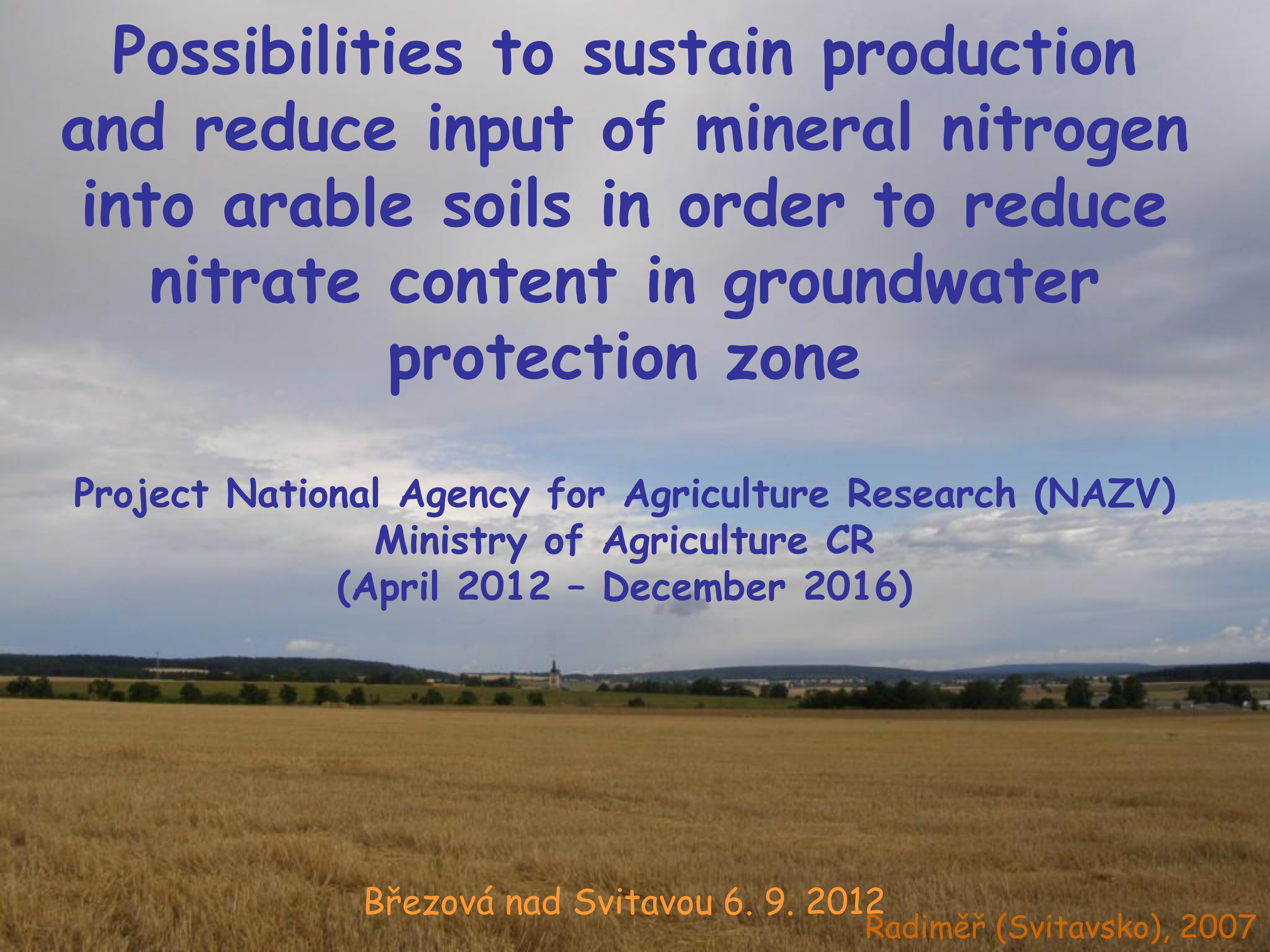
(c) Biological methods



Possibilities to sustain production and reduce input of mineral nitrogen into arable soils in order to reduce nitrate content in groundwater protection zone

Project National Agency for Agriculture Research (NAZV)
Ministry of Agriculture CR
(April 2012 – December 2016)

Březová nad Svitavou 6. 9. 2012



Radiměř (Svitavsko), 2007


48N100+C


Soil Indicators: - „*in situ*“ soil respiration; „*in situ*“ leaching of mineral nitrogen; above- and below- ground primary production

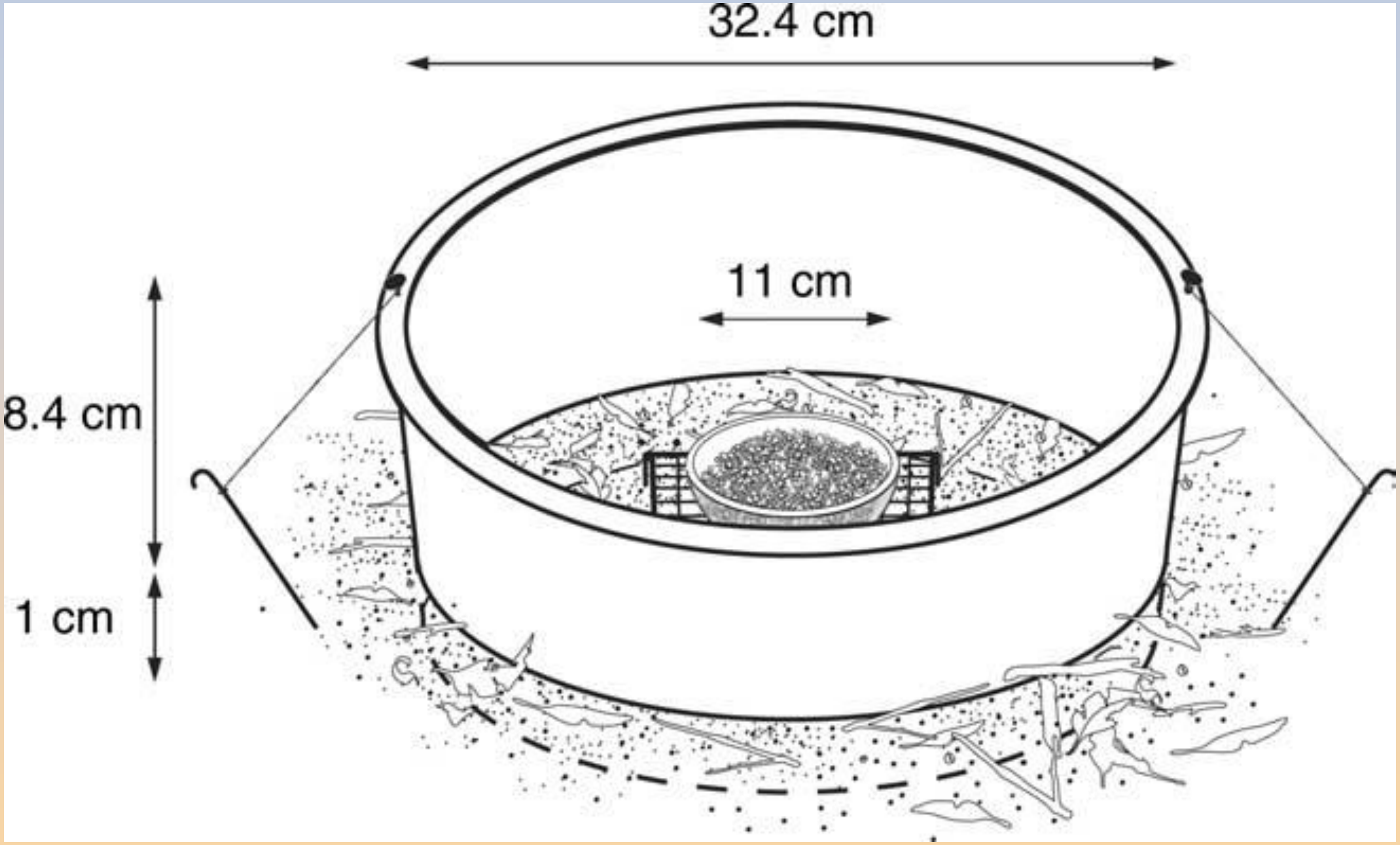
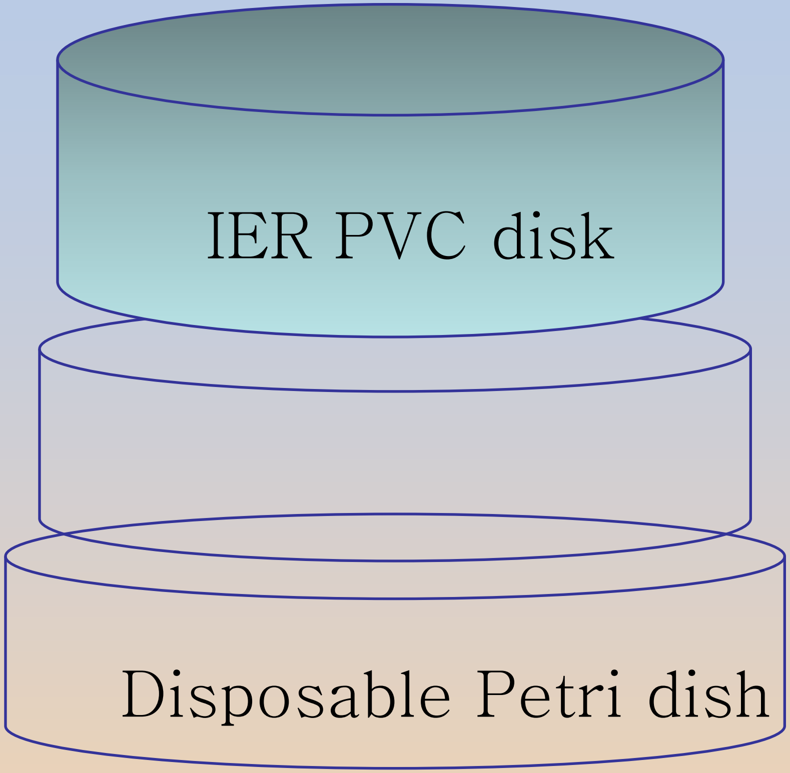
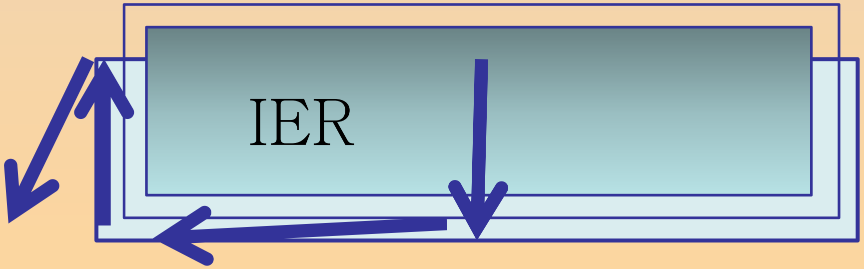


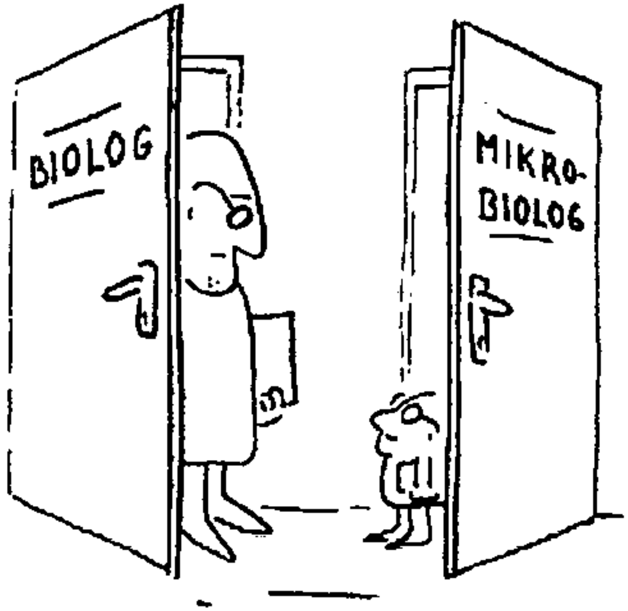
Diagram illustrating the chamber design inserted in the soil, with petri dish of soda lime on wire stand. A lid is fitted on the chamber during incubation periods.

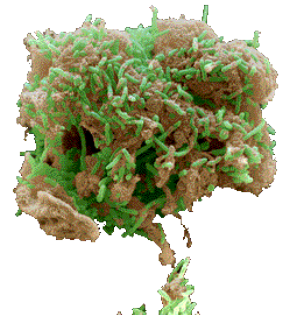
H. Keith, S.C. Wong / Soil Biology & Biochemistry 38 (2006) 1121–1131



Percolating soil solution







The laws of applied microbiology (David Perlman, 1980)

- The microbe is always right, your friend, and a sensitive partner;
- There are no stupid microbes;
- Microbes can and will do anything;
- Microbes are smarter, wiser, and more energetic than chemists, engineers, and others; and
- If you take care of your microbial friends, they will take care of your future.