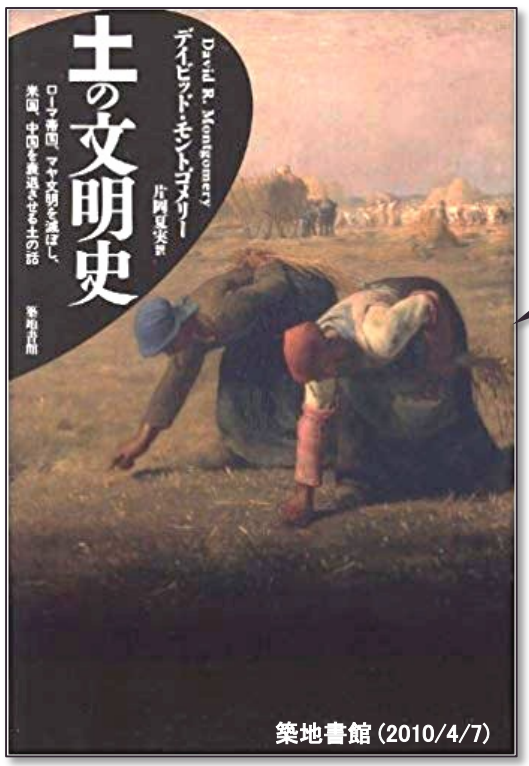
Moonshot International Symposium
December 18, 2019
Working Group 5

Utilization of microbial functions for food supply and global environmental protection

Kiwamu Minamisawa
Graduate School of Life Sciences,
Tohoku University

Soil supports food production

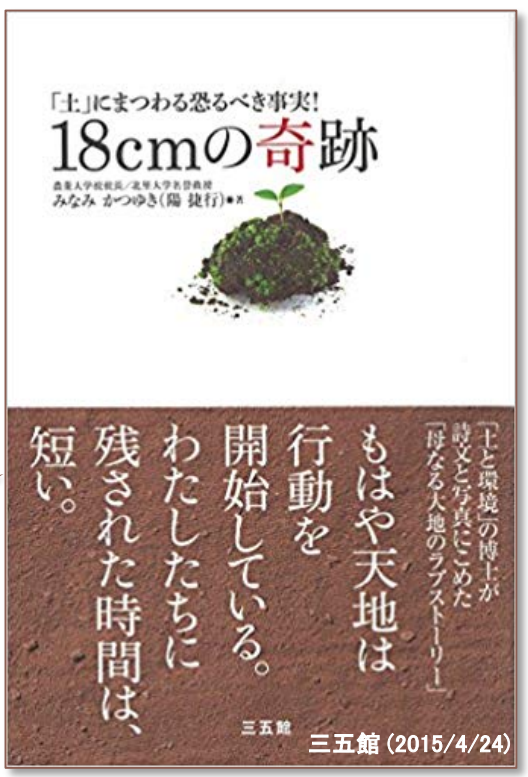
Soil is the precious resource for mankind, and exists only on the Earth



デイビッド・モントゴメリー、片岡夏実訳（2010）
土の文明史、築地書館 ISBN-10: 4806713996

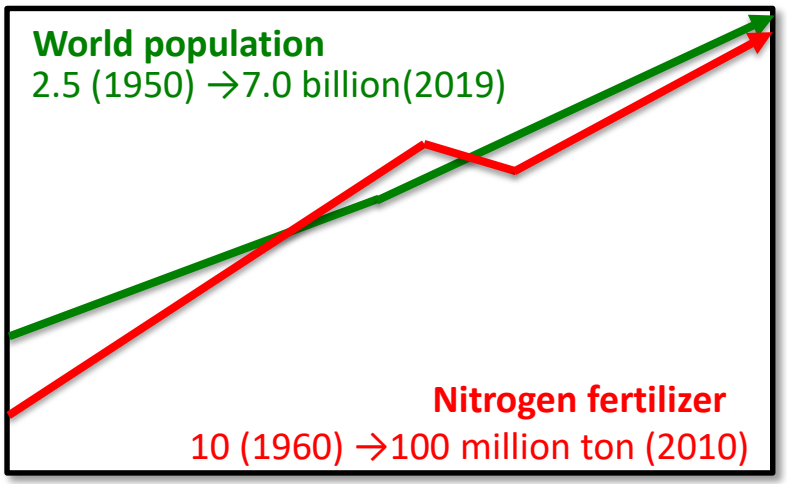
Soil loss led to the collapse of Greek & Roman civilization

陽 捷行（2015）「土」にまつわる恐るべき事実！
18cmの奇跡、三五館、ISBN-10: 4883206319



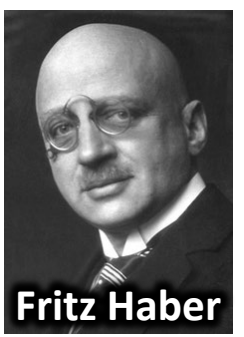
Soil is only 18 cm thick on average and present as “skin” of the Earth.

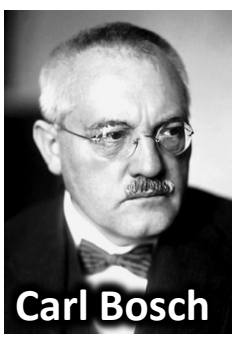
Growing population, growing use of



Haber–Bosch process

Les Prix Nobel (1919)





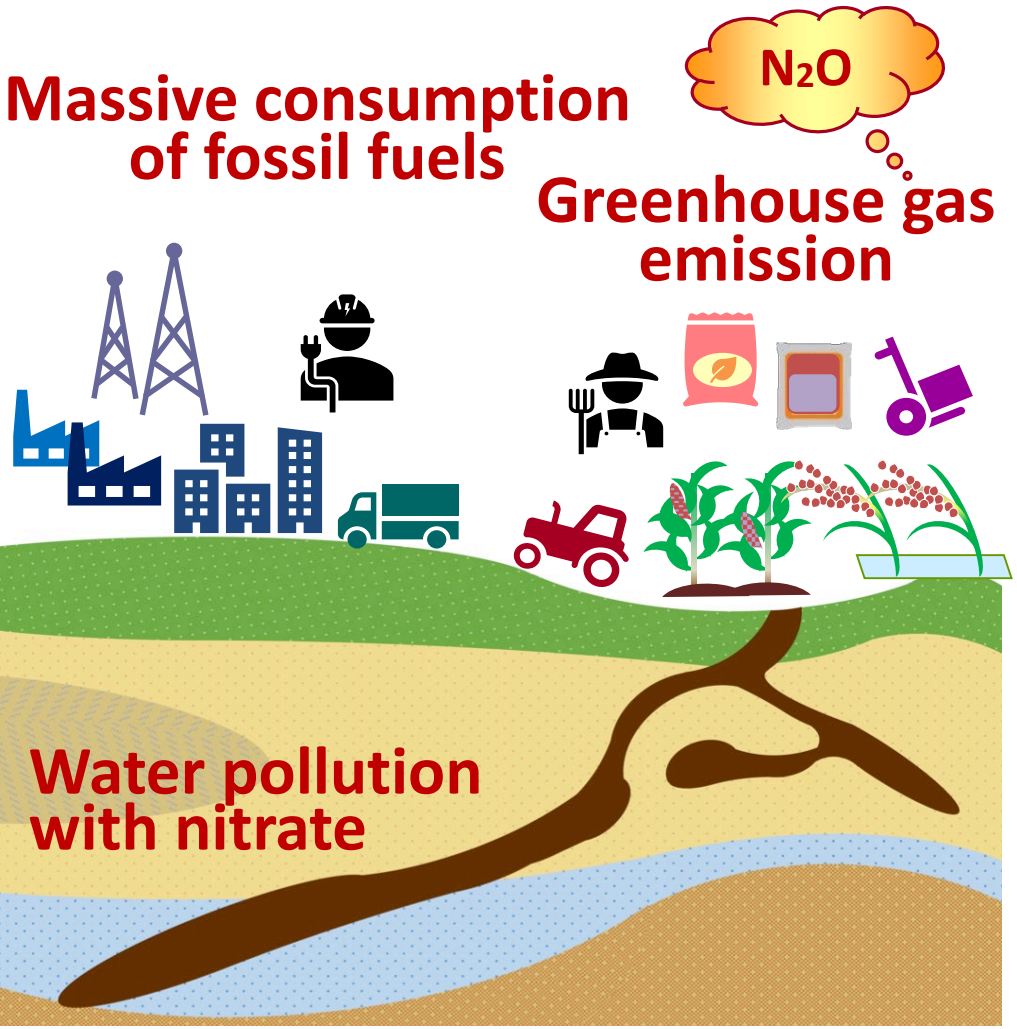
(Wikipedia)

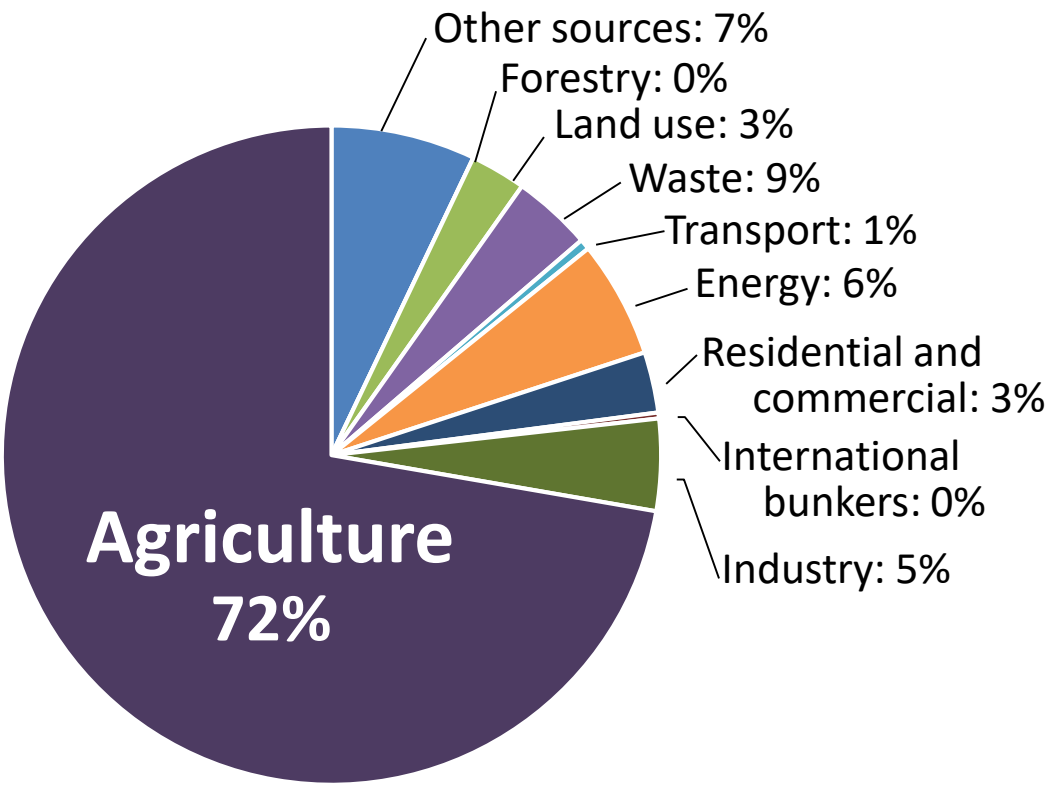
Industrial nitrogen fixation technology was invented by Fritz Harbor and Carl Bosch in the early 20th century.
Mass production of chemical nitrogen fertilizer enabled rapid population increase.

Three percents of the world's fossil fuels is consumed by industrial nitrogen fixation.

N_2O emission (2010)

3.06 billion tonns (in CO2 eq.)



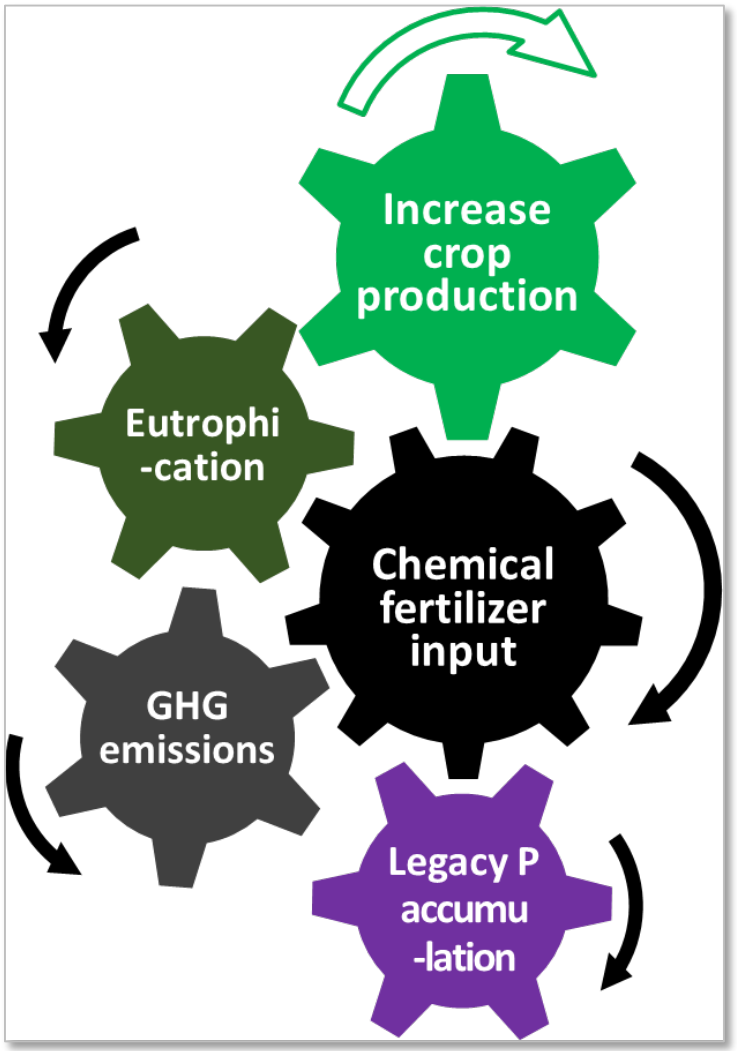


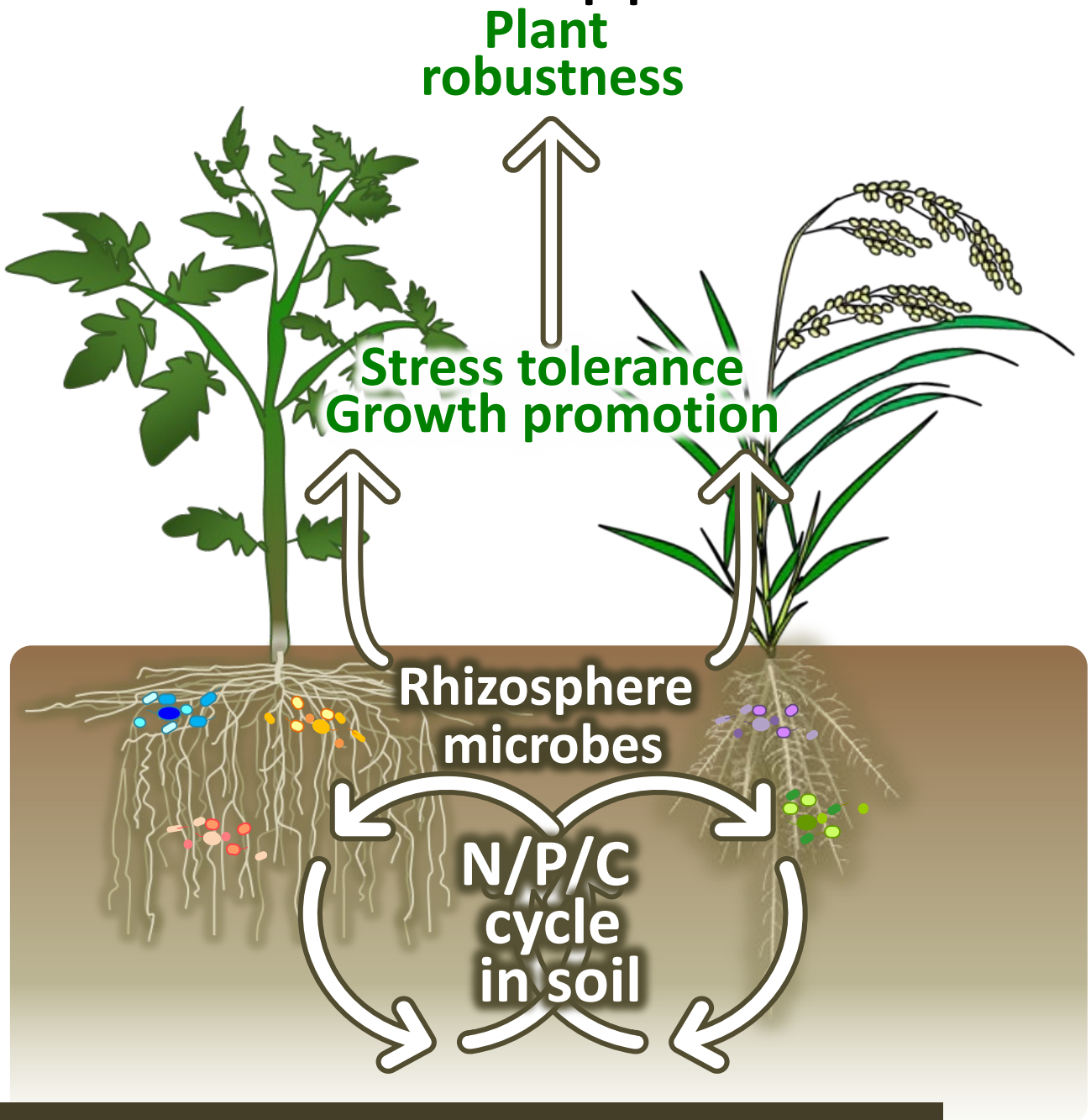
Source: Food and Agriculture Organization of the United Nations (FAO), 2017.

Agriculture contributes 72% of the total N_2O emissions.

Importance of soil-microbe research for crop production

The Green Revolution





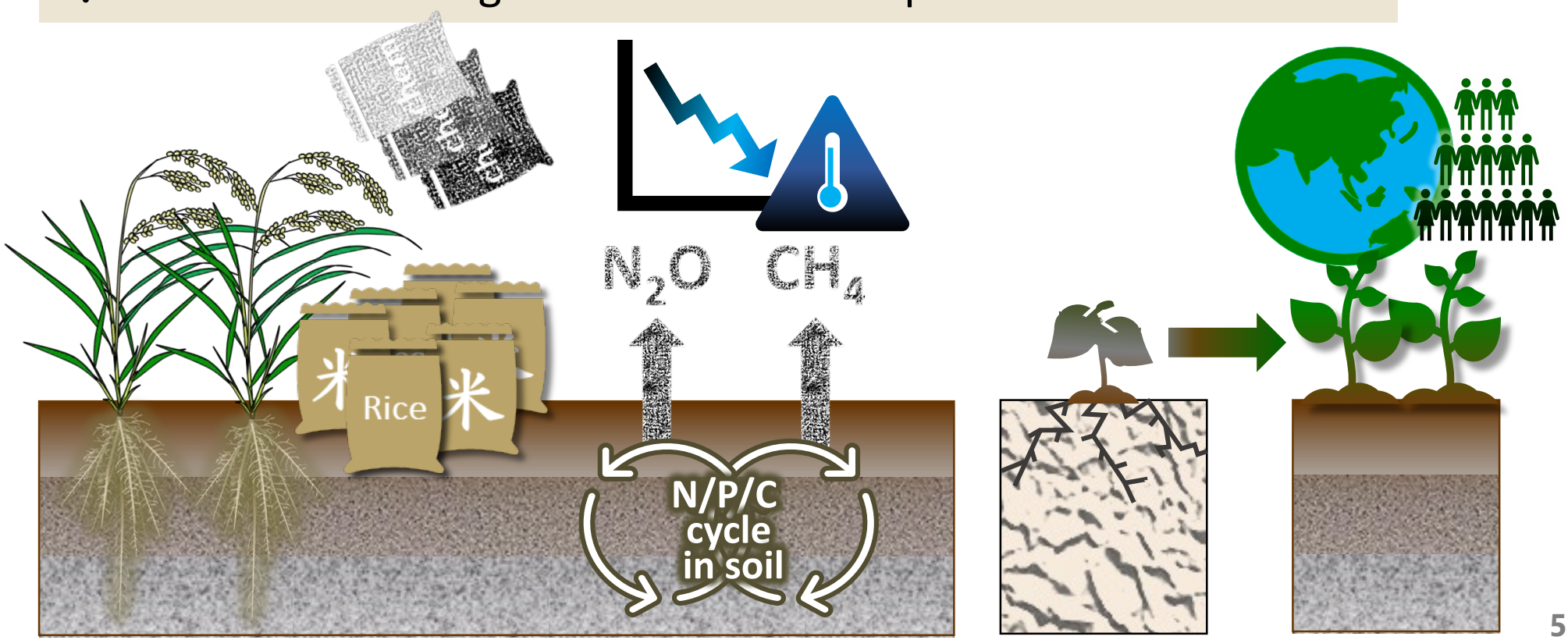
Plant-microbiome shapes the Nitrogen/Phosphorus/Carbon cycle in soil.

A candidate of Moonshot targets

Complete regulation of soil microbial environments
towards zero chemical fertilizer and greenhouse gas reduction

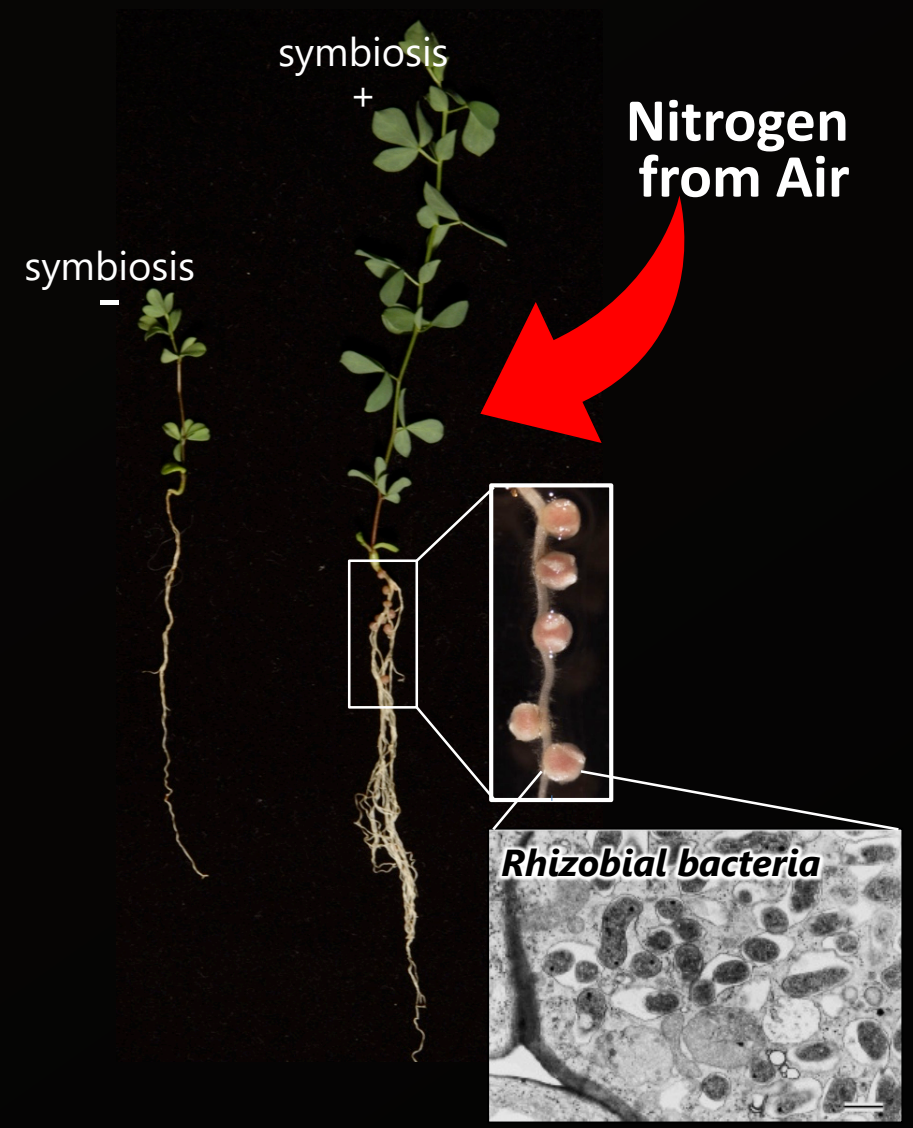
This goal consist of three parts;

1. Increase of crop production without chemical fertilizers
2. Reduction of the greenhouse gases derived from agriculture
3. Restoration of degraded soils for food production

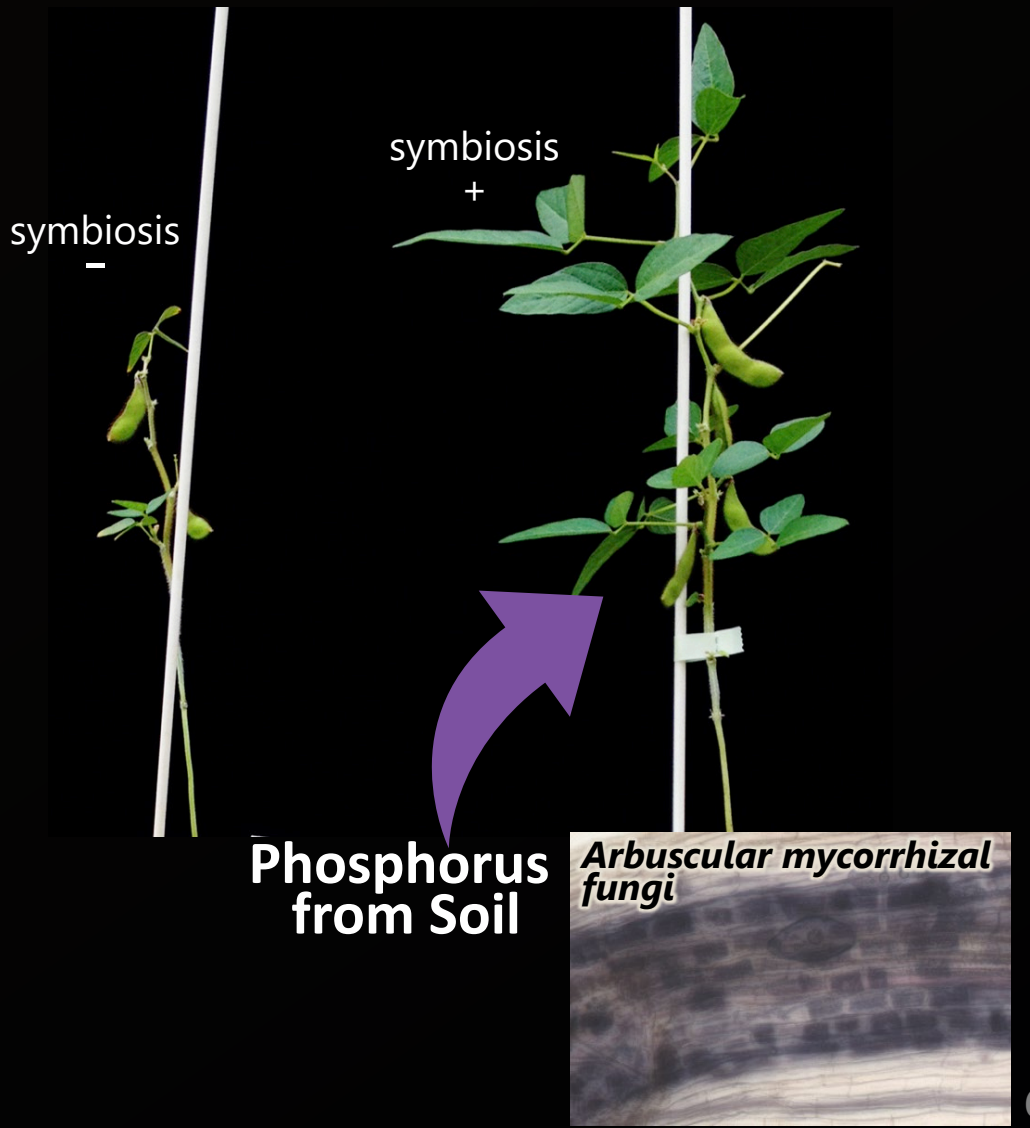


Impacts of plant-microbe symbioses on plant growth

Nitrogen Fixation by Root Nodule Symbiosis

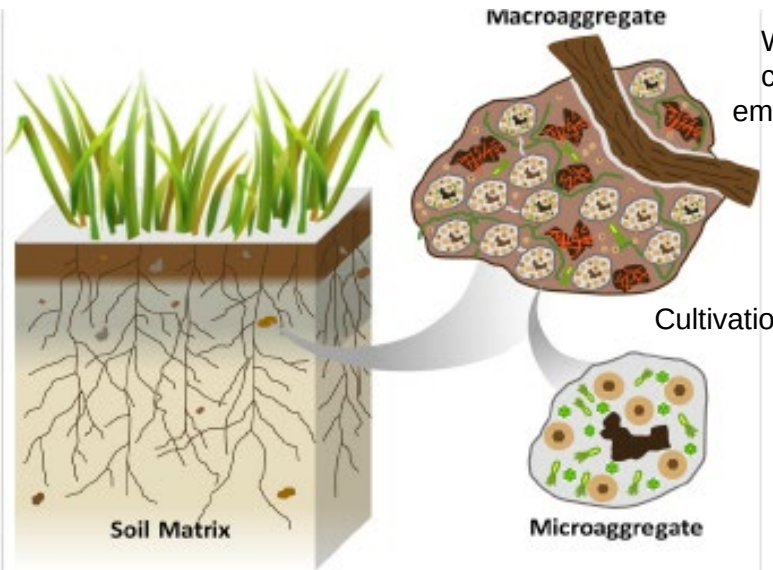


Phosphorus Uptake by Arbuscular Mycorrhizal Symbiosis



What are the research bottlenecks?

- Due to the complexity of microbial processes in agroecosystem, it is difficult to regulate Nitrogen/Phosphorus/Carbon cycles, GHG mitigation and interactions.
- More than 99% of microbes in agricultural fields have not yet been cultured due to the limitations of conventional culture techniques.
- Soil microbes lives in complex soil structures where nutrient/gas exchanges and communications are drastically fluctuated along with space and time.

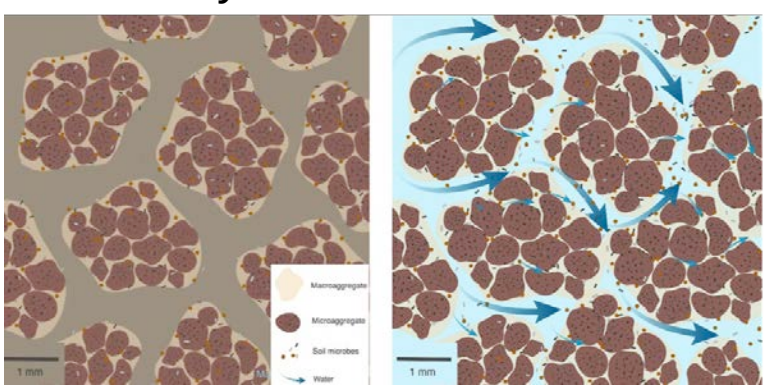


Where do N/P/C cycles and GHG emission happened?

Cultivation?

How are communications and nutrient/gas flows?

Dry Wet

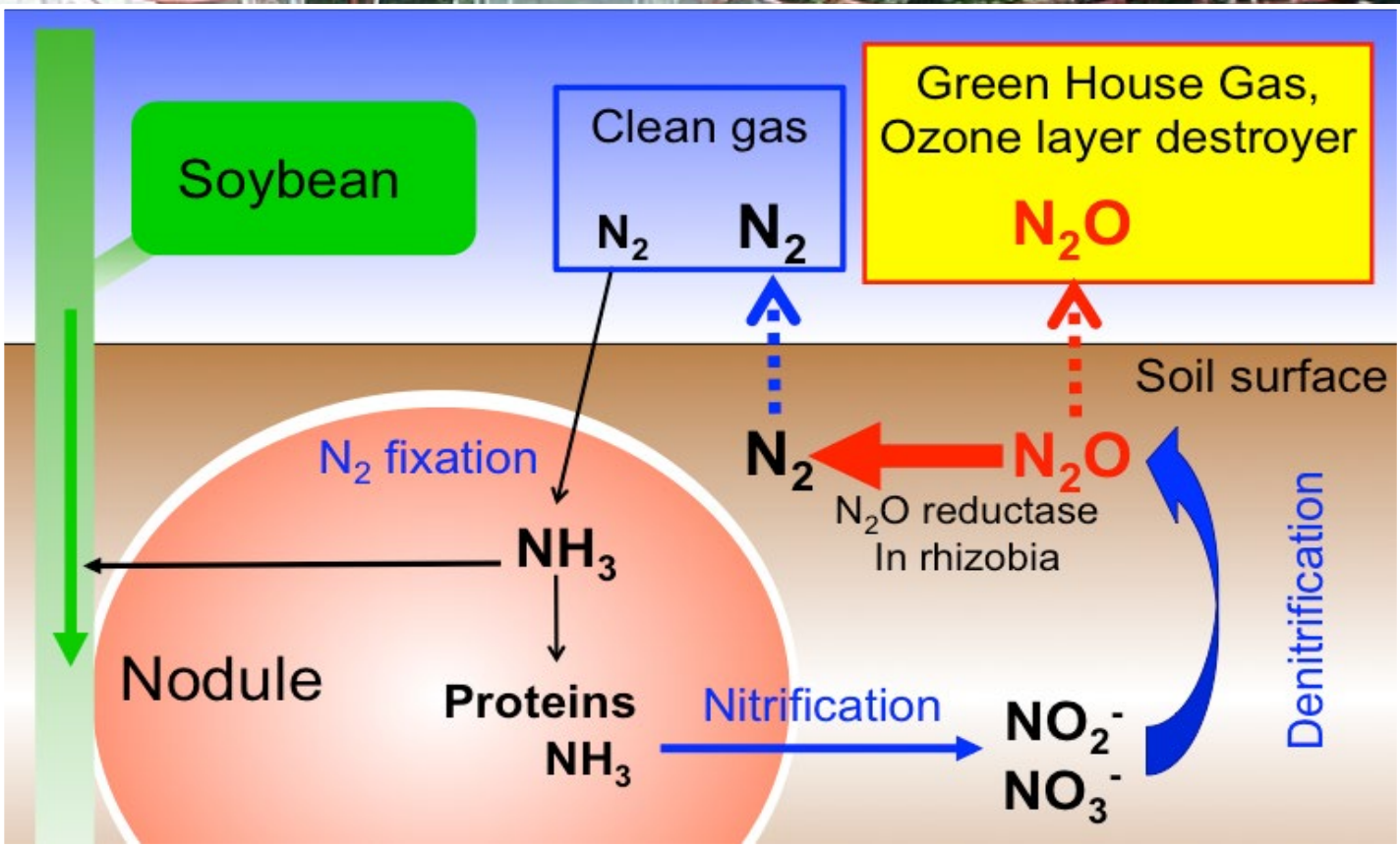


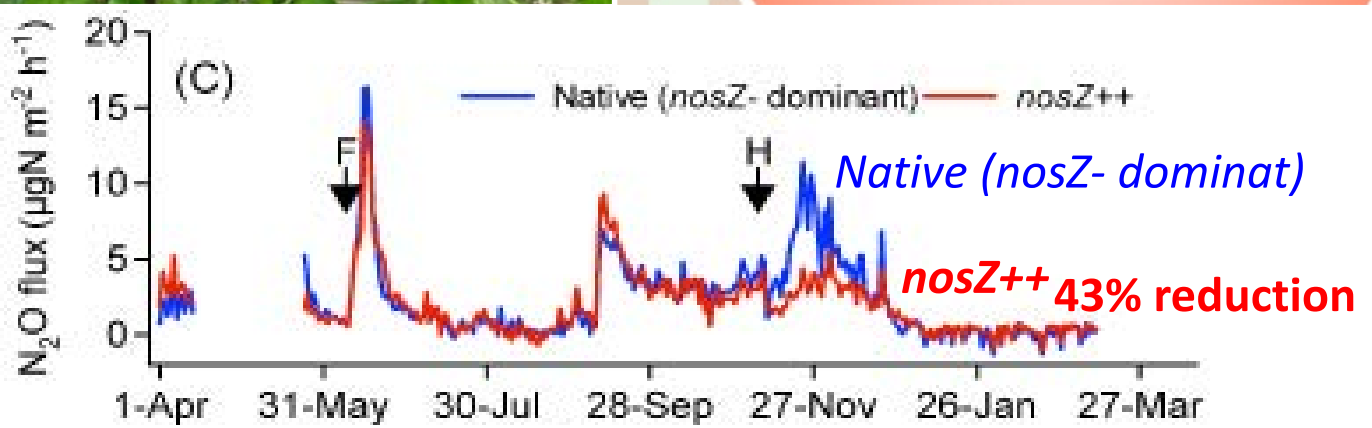
Wilpiszeski *et al*. 2019

New technologies and ideas are developing to overcome these bottlenecks.

Mitigation of nitrous oxide emissions from soils by rhizobial inoculation.

Itakura et al. (2013) Nature Climate Change





Native (nosZ- dominat)

nosZ++ **43% reduction**

This is a novel option to mitigate biologically N2O emission in field level.

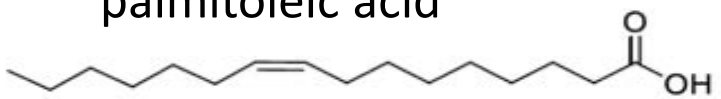
Mycorrhizal symbiosis: the most fundamental mutualistic plant-microbe interaction
Arbuscular mycorrhizal (AM) fungi: obligate symbionts that cannot live without host plants

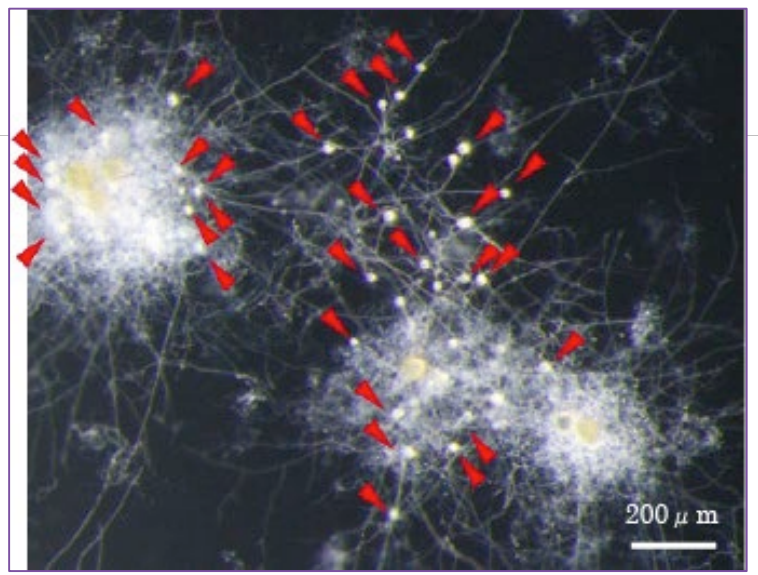
nature microbiology
LETTERS
https://doi.org/10.1038/s41564-019-0485-7

Stimulation of asymbiotic sporulation in arbuscular mycorrhizal fungi by fatty acids

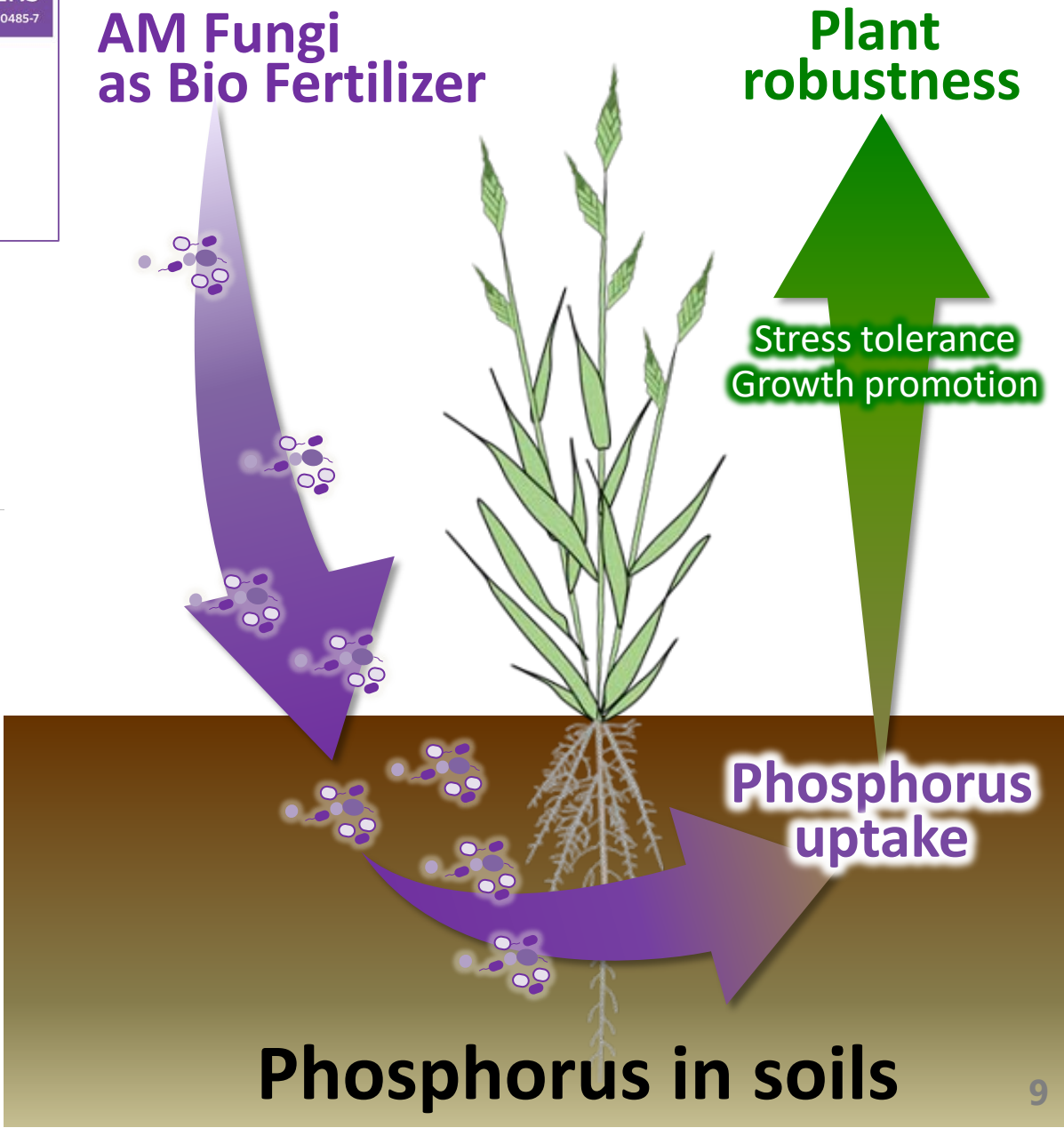
Hiromu Kameoka[1,7], Ippo Tsutsui[2,7], Katsuharu Saito[3,4], Yusuke Kikuchi[5], Yoshihiro Handa[1], Tatsuhiro Ezawa[5], Hideo Hayashi[2], Masayoshi Kawaguchi[1,6] and Kohki Akiyama[2*]

palmitoleic acid





The world's first successful cultivation of arbuscular mycorrhizal fungi opens the path to mass production of AM fungi as microbial fertilizer



Core microbiomes for resource-efficient and stress-resistant agroecosystems

nature plants

PERSPECTIVE

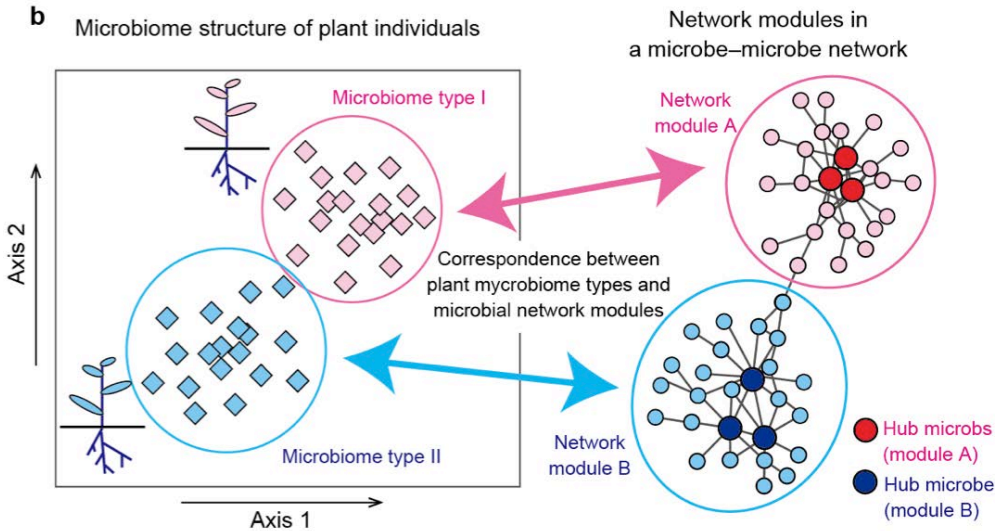
https://doi.org/10.1038/s41477-018-0139-4

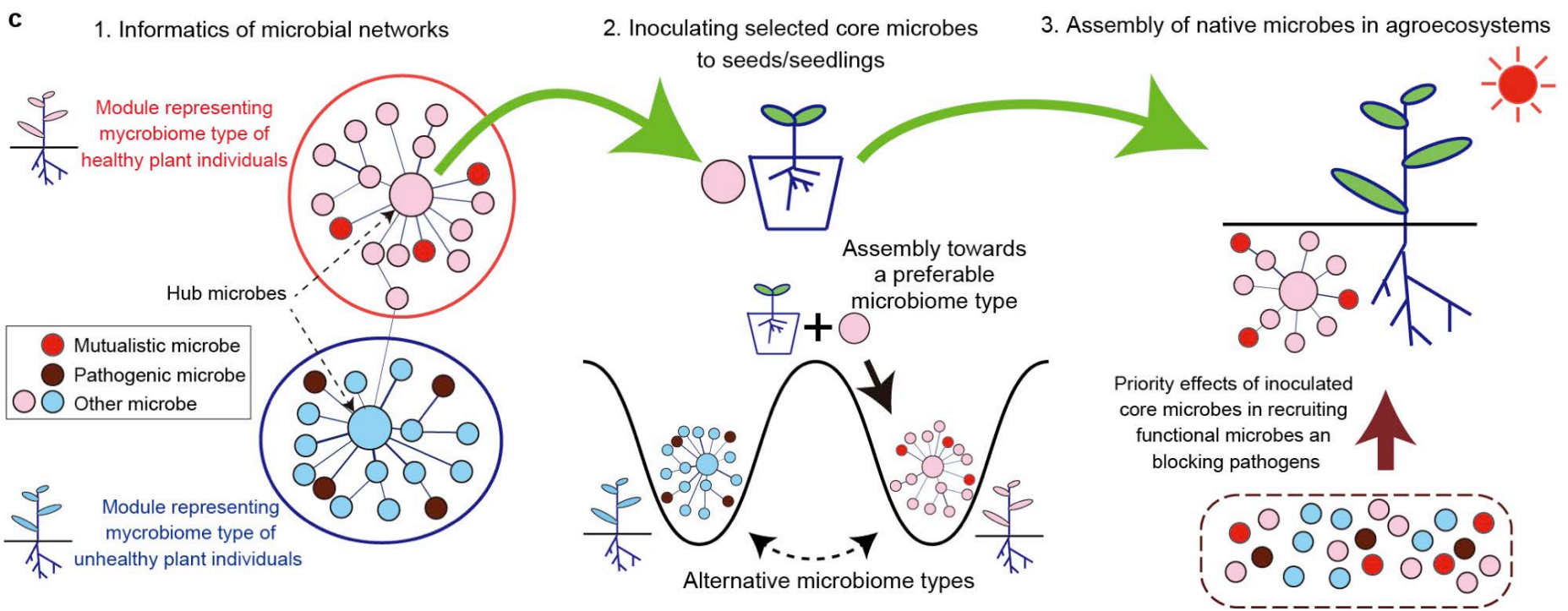
Core microbiomes for sustainable agroecosystems

Hirokazu Toju[1,2*], Kabir G. Peay[3], Masato Yamamichi[4], Kazuhiko Narisawa[5], Kei Hiruma[2,6], Ken Naito[7], Shinji Fukuda[2,8,9,10], Masayuki Ushio[1,2], Shinji Nakaoka[2,11], Yusuke Onoda[12], Kentaro Yoshida[2,13], Klaus Schlaeppi[14,15], Yang Bai[16,17], Ryo Sugiura[2,18], Yasunori Ichihashi[2,19,22], Kiwamu Minamisawa[20] and E. Toby Kiers[21]

Hot Paper

Highly Cited Paper



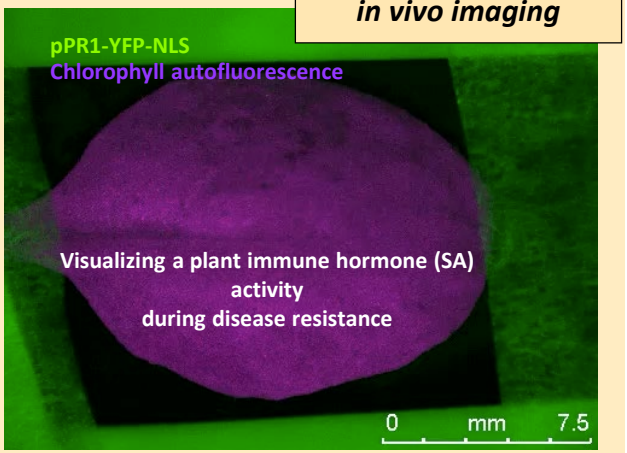


JST ERATO

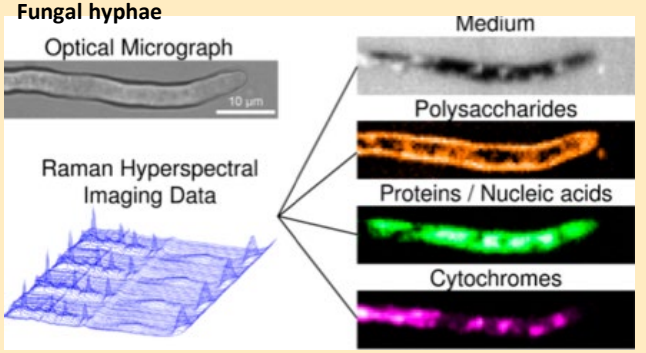
“NOMURA Microbial Community Control Project” FY2015~FY2020

***Visualizing* the life of microbes in communities**
towards *regulating* microbial communities related to human life

in vivo imaging



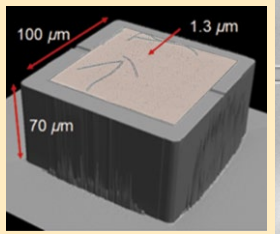
Raman

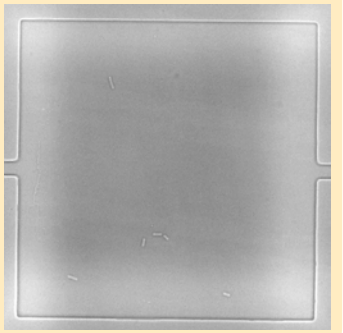


(Yasuda et al, Anal Chem 2019)

Microfluidics

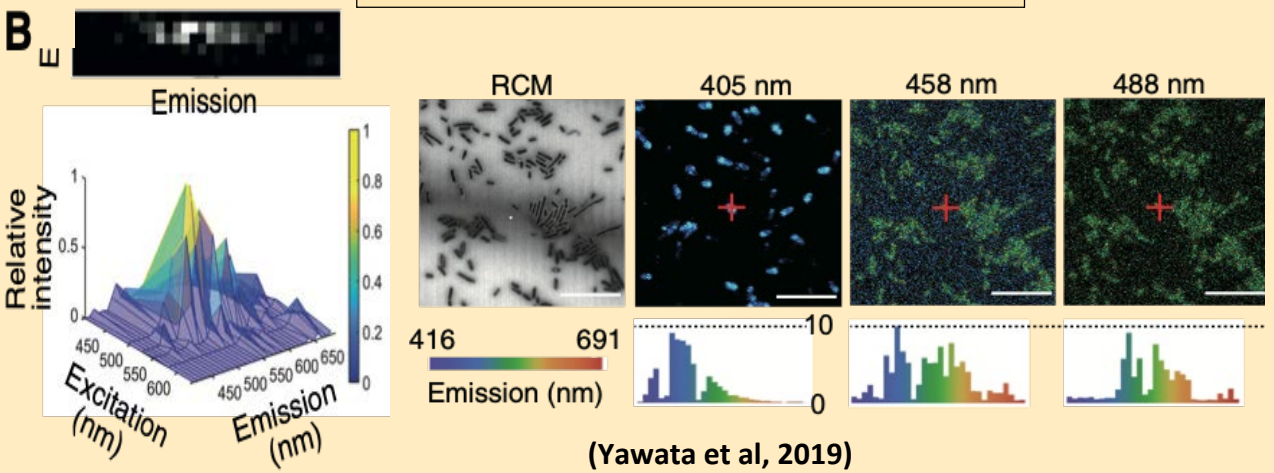
***Leptothrix cholodnii* growth in a “2D” plane**





(Kunoh et al, ACS nano 2019)

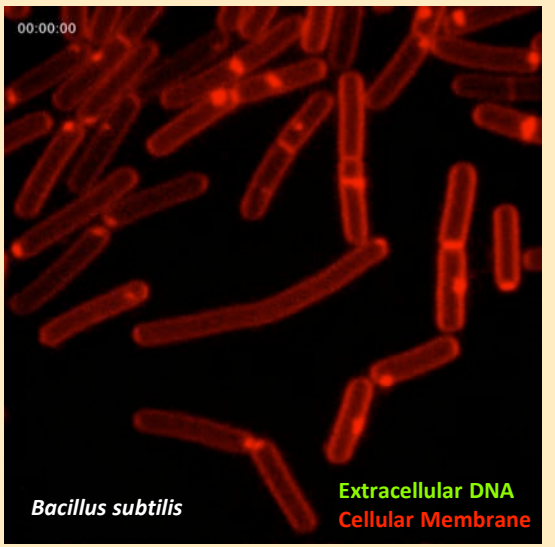
Auto-fluorescence (CRIF technology)



(Yawata et al, 2019)

Explosive Cell Death for MV production

The imaging-based study revealed a hitherto unknown MV production mechanism conserved among bacteria.



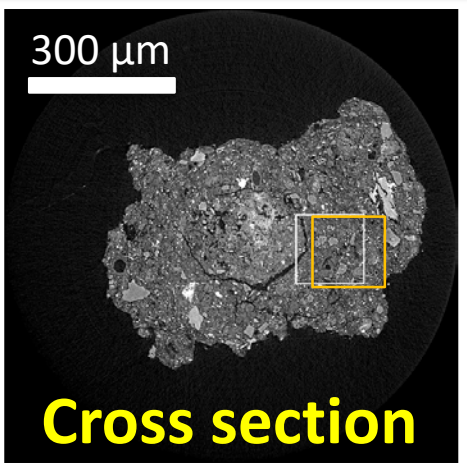
(Toyofuku et al, Nat Commun 2016, Toyofuku et al, Nat Rev Microbiol 2019)

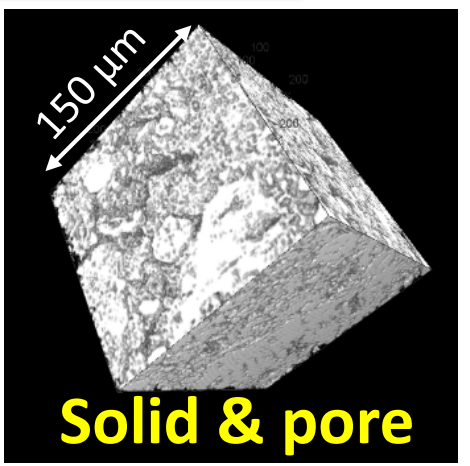
Visualization of pore & OC in 3D aggregate structure

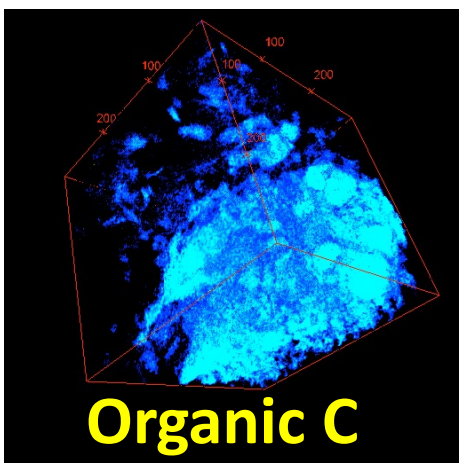
An improved method to identify osmium-stained organic matter within soil aggregate structure by electron microscopy and synchrotron X-ray micro-computed tomography

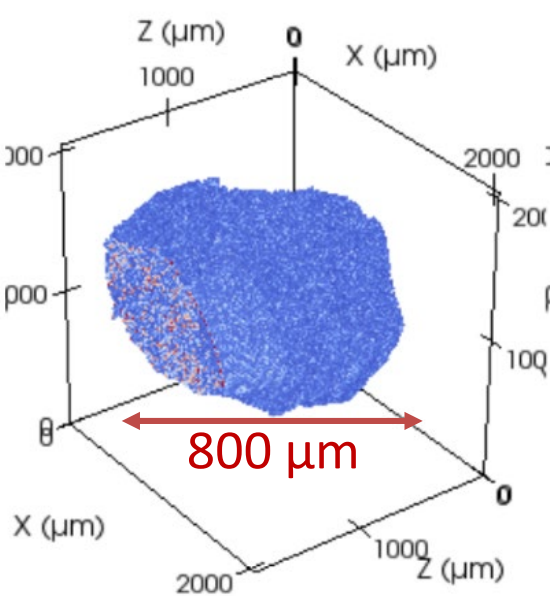
Miwa Arai[a,1], Go-Ichiro Uramoto[b,1], Maki Asano[c], Katsuyuki Uematsu[d], Kentaro Uesugi[e], Akihisa Takeuchi[e], Yuki Morono[f,g,**], Rota Wagai[a,*]

Arai et al. 2019.
Soil & Tillage Res.









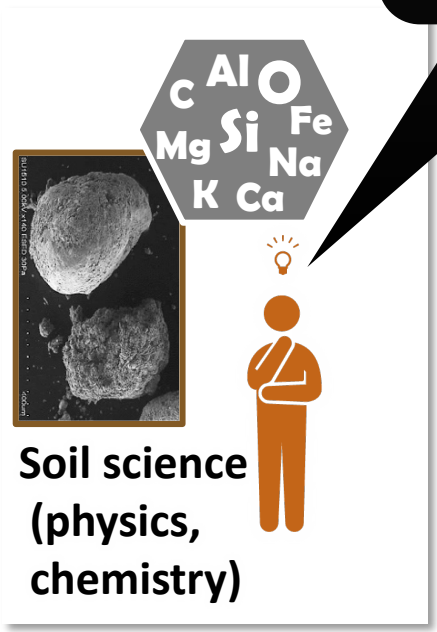
- Pore network = habitat & exchange of water/oxygen
- Organic C = substrate, aggregate binding agent
- Spatial resolution: 0.5 µm ~ bacterial cell size

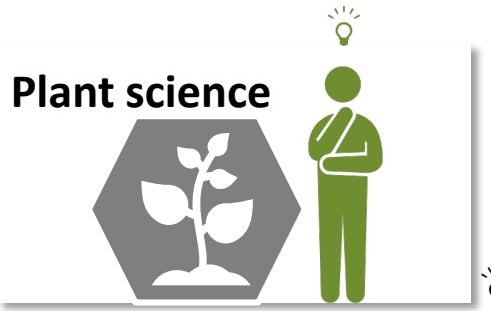
Now in collaboration with Germany (Uni Kassel) & France (INRA)

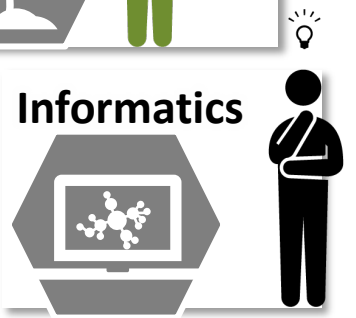
Synchrotron X-ray micro CT: SPring-8 BL20XU

Biggest researcher bottleneck?

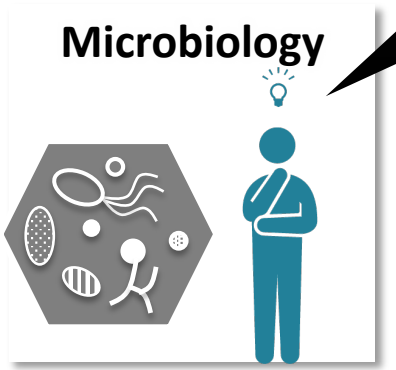
No, because soils are diverse and variable with space and time

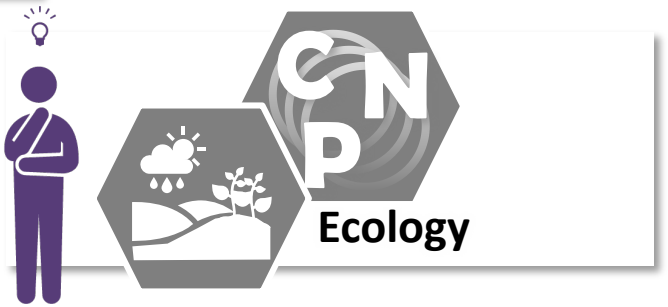






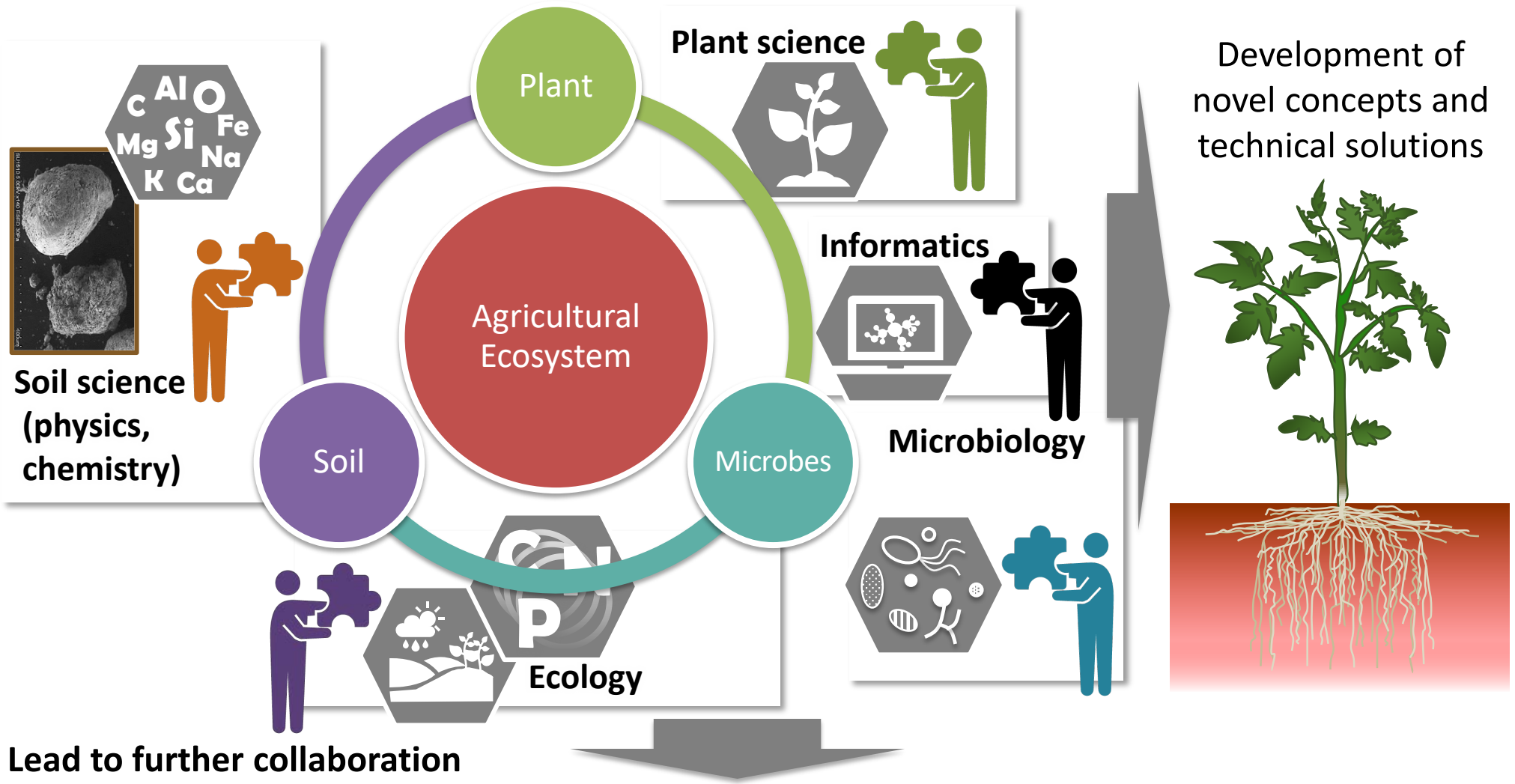
Is there a standard soil for microbiology like agar plates?





Biggest researcher bottleneck?

<u>Novel interdisciplinary collaboration</u> are required for complete understanding and regulation of soil microbes

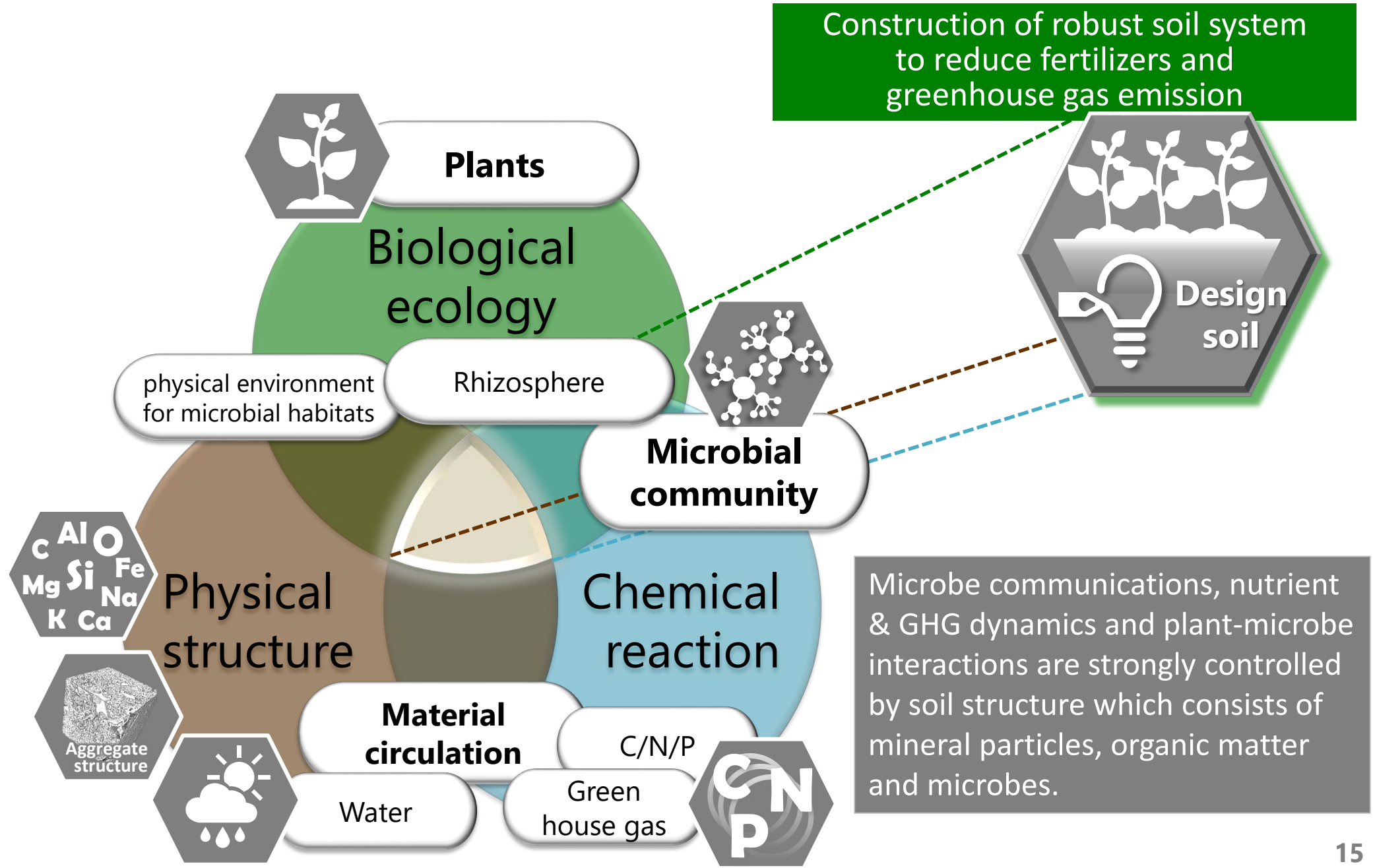


Lead to further collaboration

All societal actors (researchers, policy makers, business, third sector organizations, farmers, citizens etc.) work together toward the common vision.

Example of research concept/ 1

Interactions between structured soils and microbial community functions

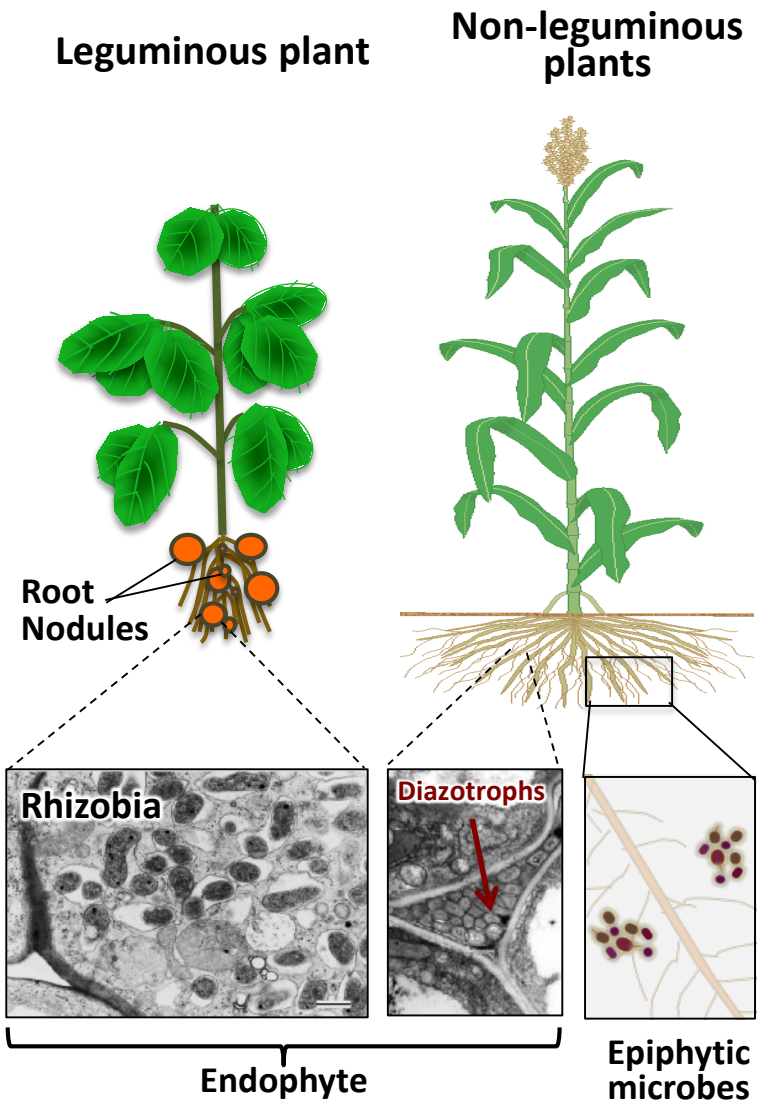


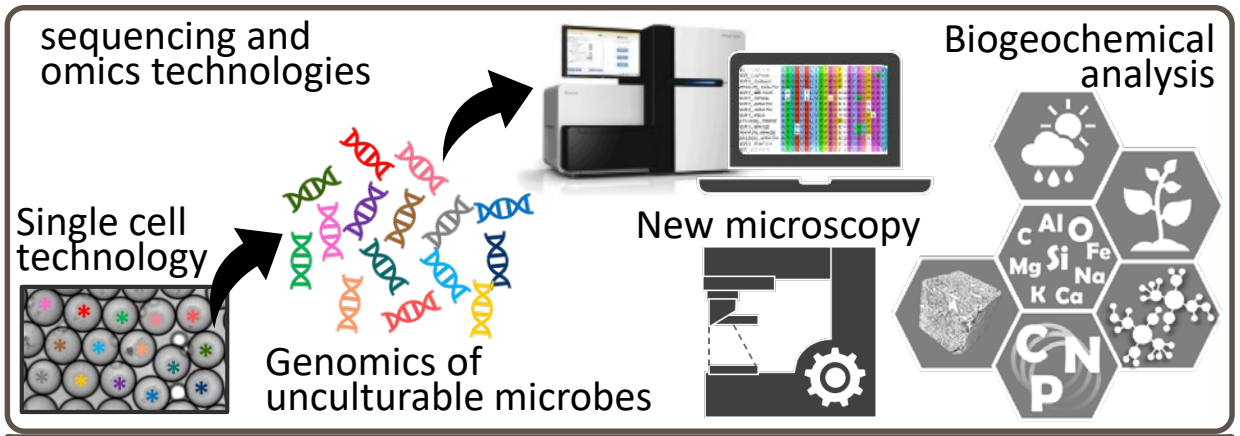
Microbe communications, nutrient & GHG dynamics and plant-microbe interactions are strongly controlled by soil structure which consists of mineral particles, organic matter and microbes.

Example of research concept/ 2

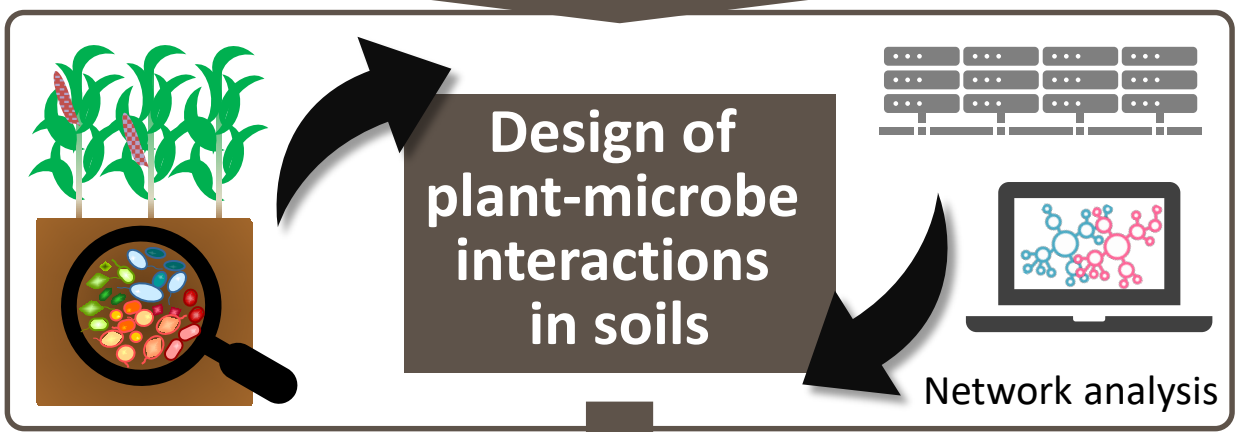
Microbial nitrogen fertilizers in upland fields

The diazotrophs : N_2-fixing soil bacteria





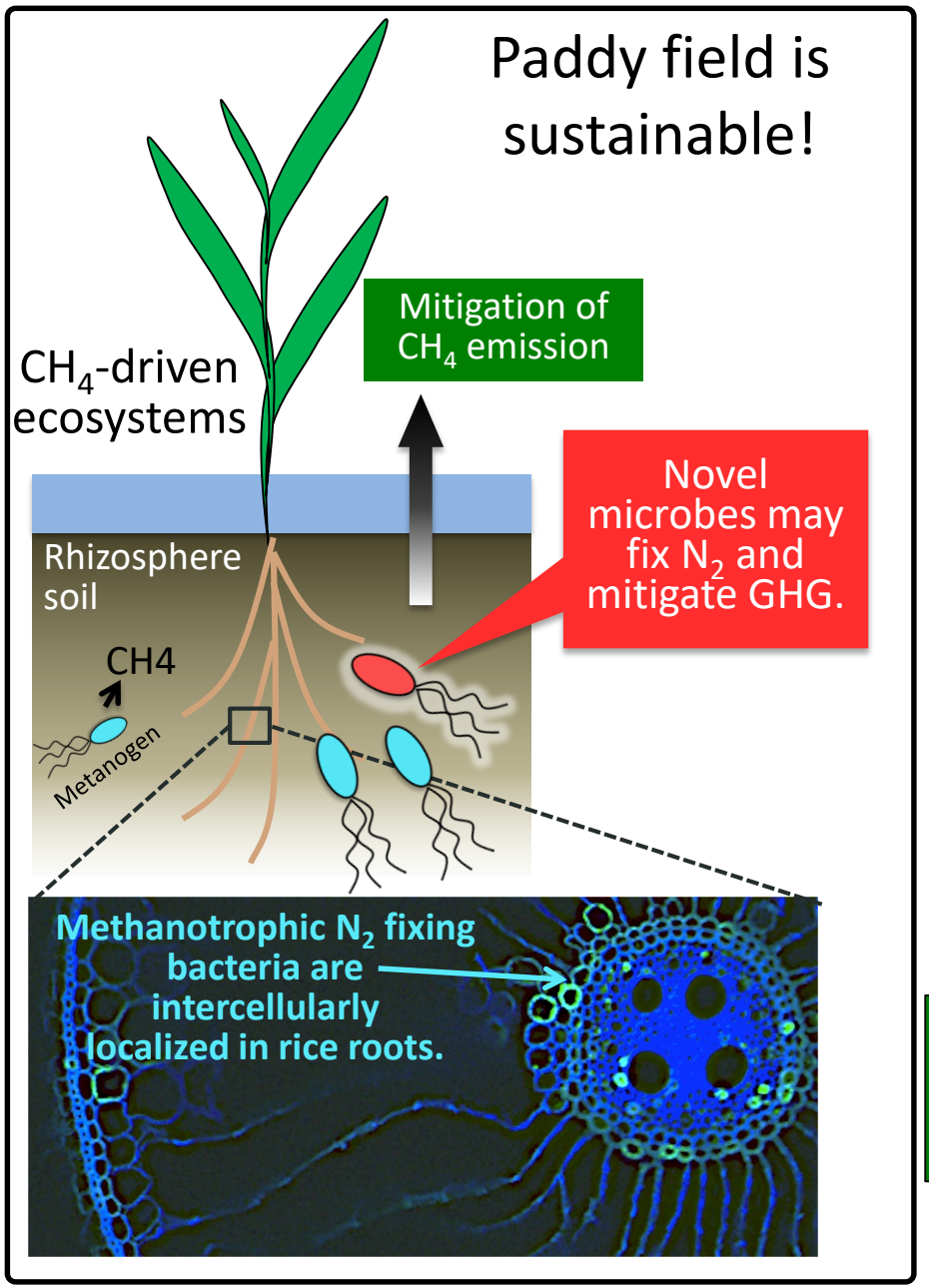
Visualization and community analysis



Increase of crop production without N fertilizers

Example of research concept/ 3

Microbial nitrogen fertilizers and greenhouse gas (GHG) mitigation in rice paddy



CH_4-oxidation dependent methanotrophic N_2 fixation provides a potential route to reduce CH_4 emissions

Recent preliminary studies

1) Fe redox-mediated N_2 fixation
2) Anaerobic N_2O reducers
3) ……

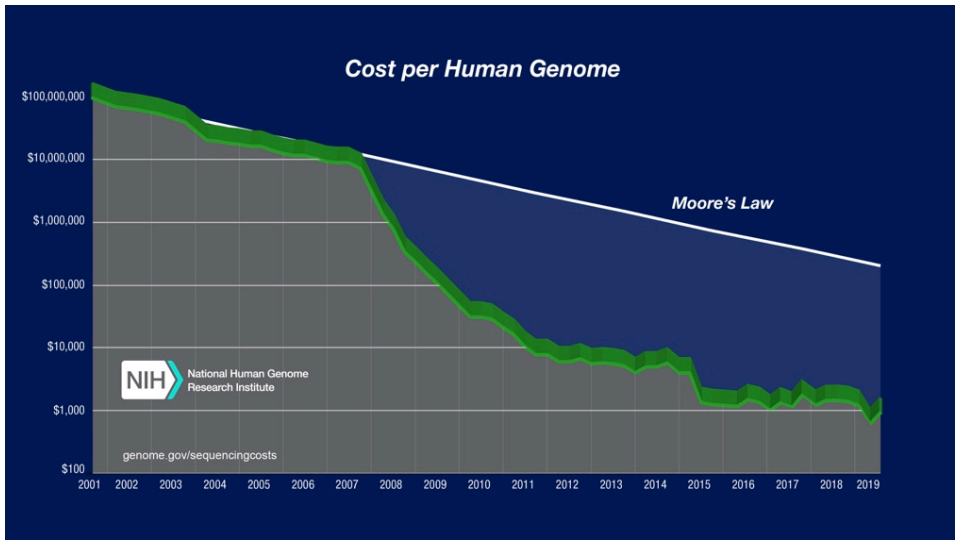
Complete understandings of rice paddy system

Mitigation of GHG emission from rice paddy field.

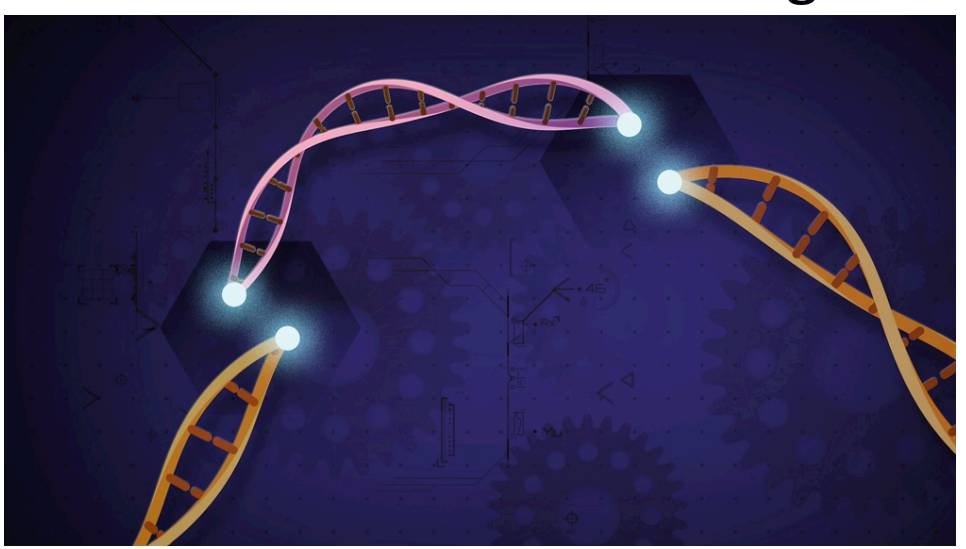
Rice cultivation without N fertilizers.

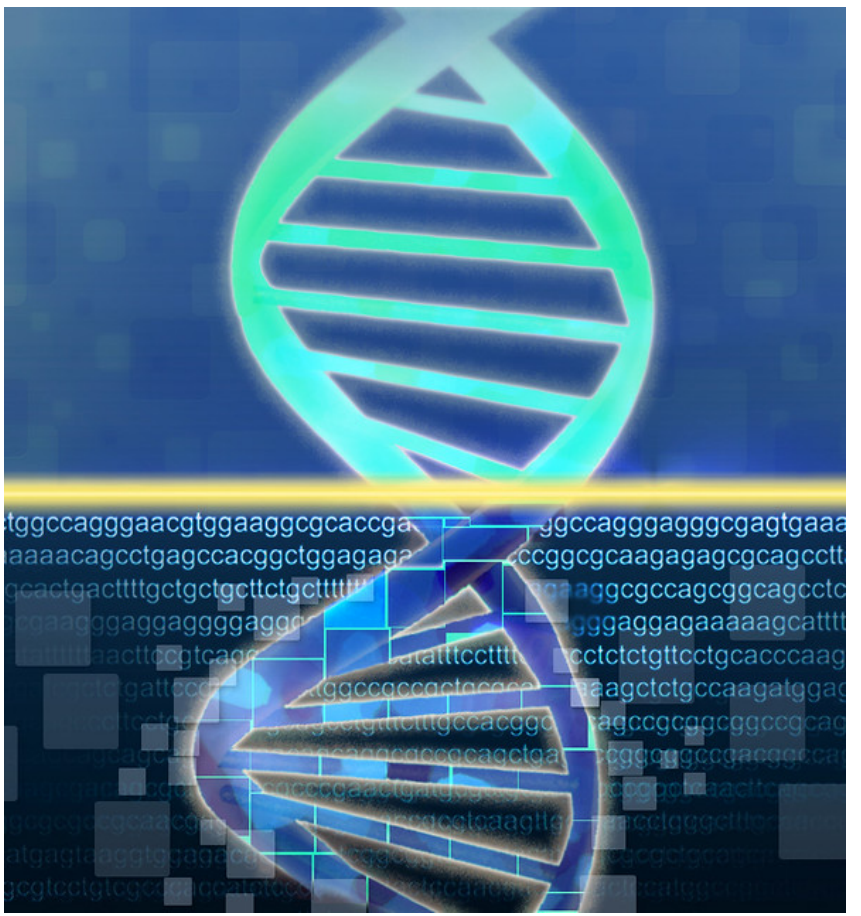
Information and Biology: The past and next 30 years

1990 Kilo → 2020 Tera (10^{12}) → 2050 Zetta (10^{21})



1990 Read → 2020 Edit → 2050 Program





Toward the era of

***In situ* genome analysis &**

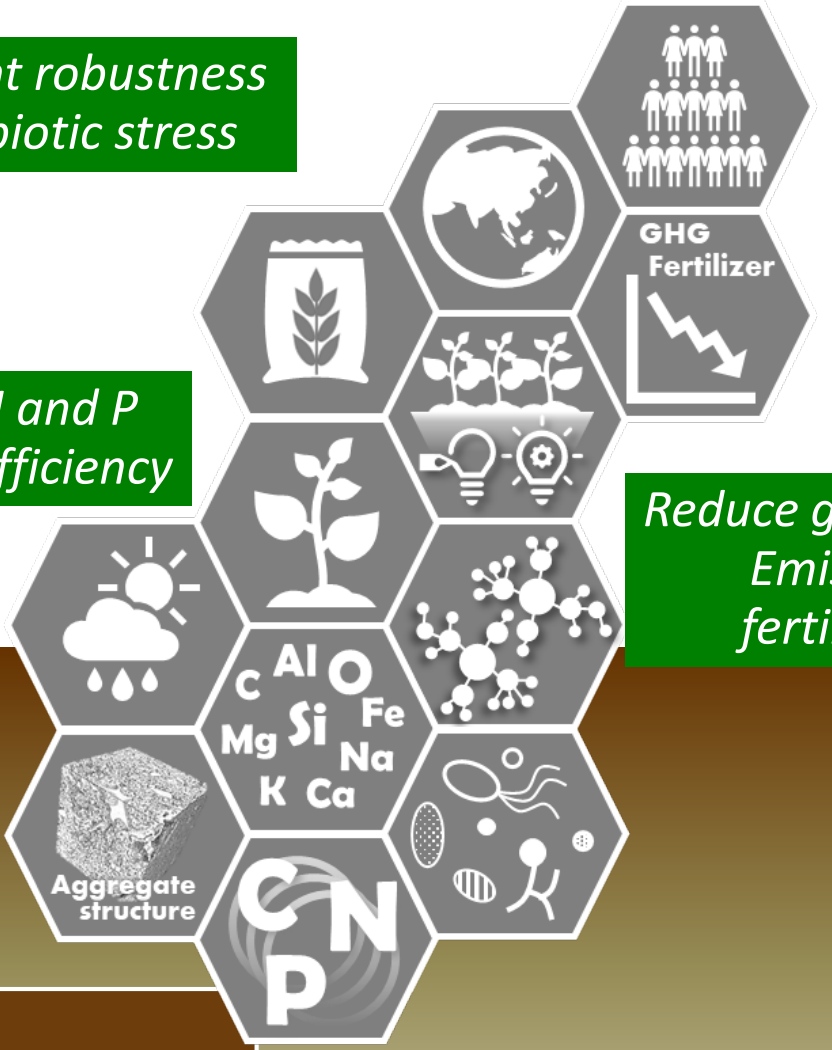
Ecosystem programming

Courtesy: National Human Genome Research Institute

Designing soil-plant-microbe systems via interdisciplinary research

Increase plant robustness to biotic/abiotic stress

Increase N and P utilization efficiency



Reduce greenhouse gas Emission and fertilized input

Optimization of Nitrogen/Phosphorus/Carbon dynamics

Optimization of Plant-microbes interaction in rhizosphere

Microbial genome program

What kind of future can be opened ?

Zero fertilizers
Prevent global warming

Mars

Terraforming

Earth

NASA HP

Summary: Necessary direction for Moonshot Research work

Create food production systems that can both increase human food supply and conserve the global environment

1. Strong agriculture, forestry, and fishery systems

- Sharply increase productivity
- Fully automate agriculture, forestry, and fisheries

2. Utilize biodiversity and conserve the environment

- Create super-crops
- Minimize damage due to natural disasters

3. Prevent food loss

- Personalized foods
- Total waste recycling

Prevent global warming

Fully sustainable "zero fertilizer" and "zero agrochemical" farming methods

Current problems	Growing world population	Rising food demand	Food loss	Global warming	Decreasing biodiversity	More frequent natural disasters