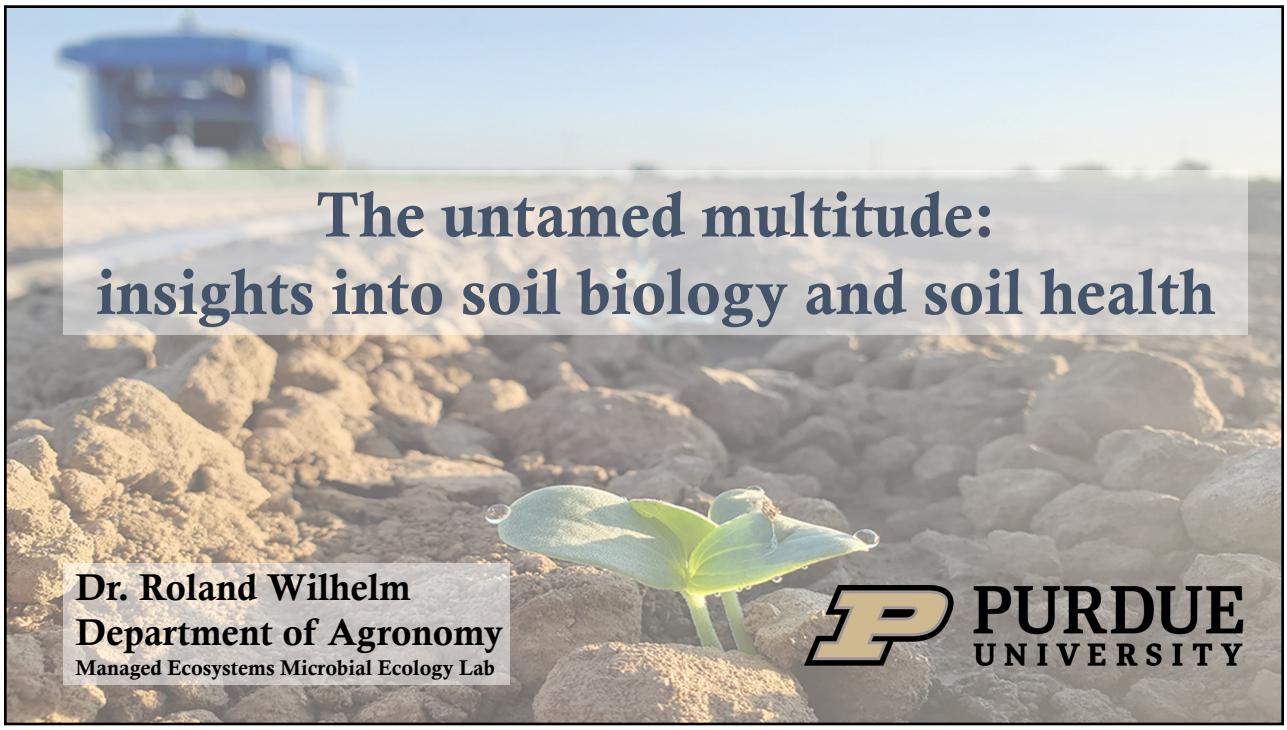
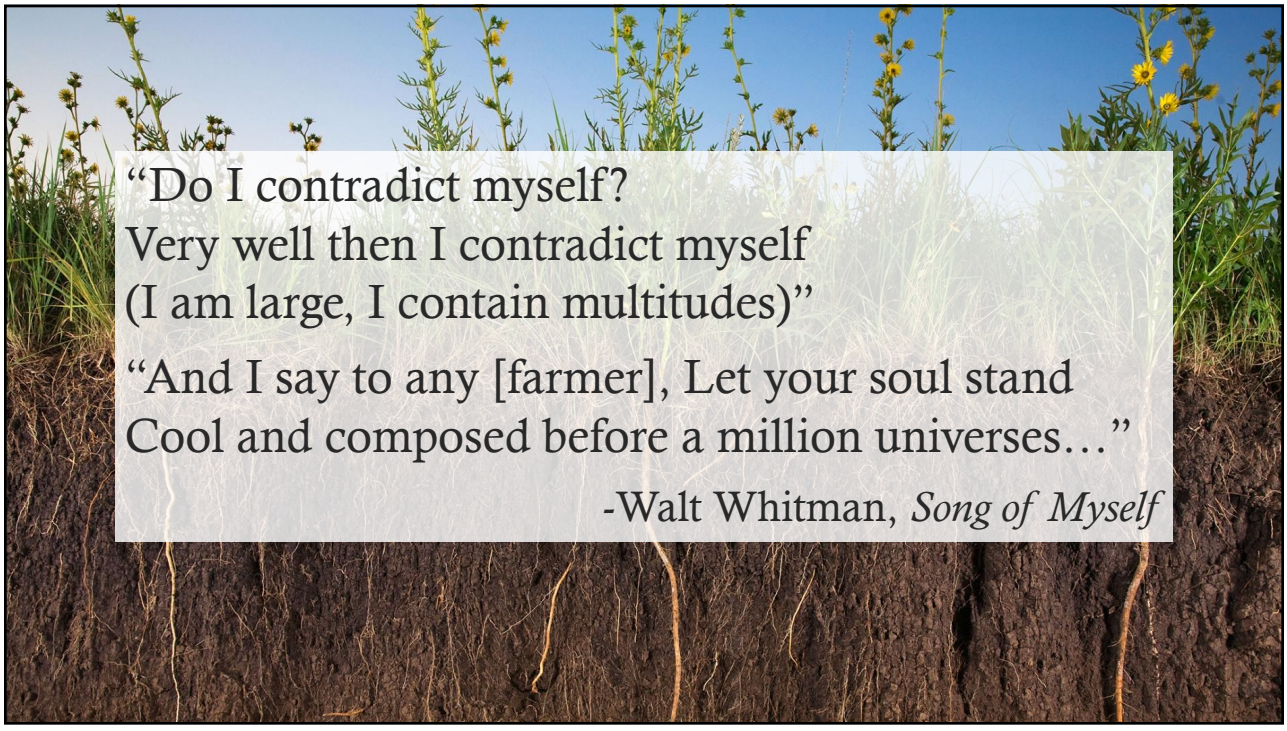
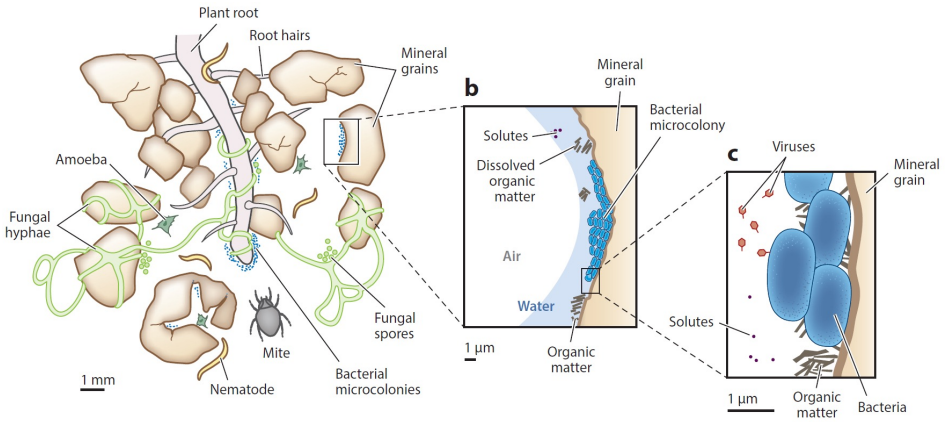

The untamed multitude:
insights into soil biology and soil health
Dr. Roland Wilhelm
Department of Agronomy
Managed Ecosystems Microbial Ecology Lab
PURDUE
UNIVERSITY

1


"Do I contradict myself?
Very well then I contradict myself
(I am large, I contain multitudes)"
"And I say to any [farmer], Let your soul stand
Cool and composed before a million universes…"
-Walt Whitman, *Song of Myself*

2

The untamed multitudes in your fields



3

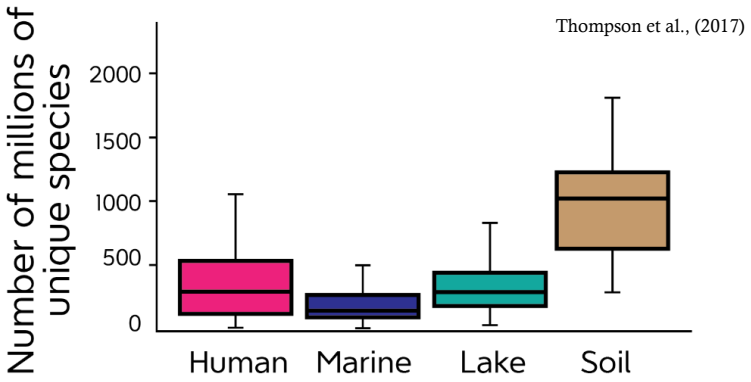
Seminar Topics

1. What makes soils unique?
2. Tackle some common questions:
   - How do soil organisms drive soil health?
   - How do I manage multitudes?
   - Is the conservation of biodiversity part of soil health?
3. Evaluating biological soil health

4

4

What makes soil biology unique?

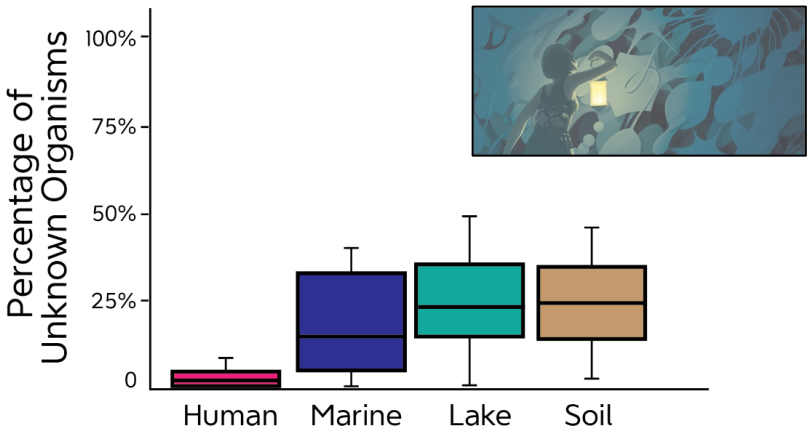


- **Higher biological diversity**

5

5

What makes soil biology unique?

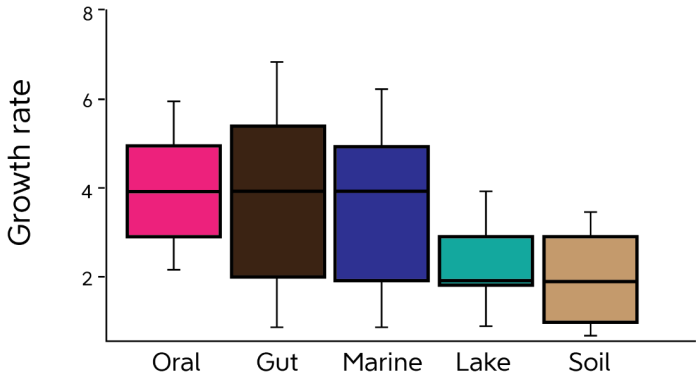


- **Novel lifeforms**

6

6

What makes soil biology unique?

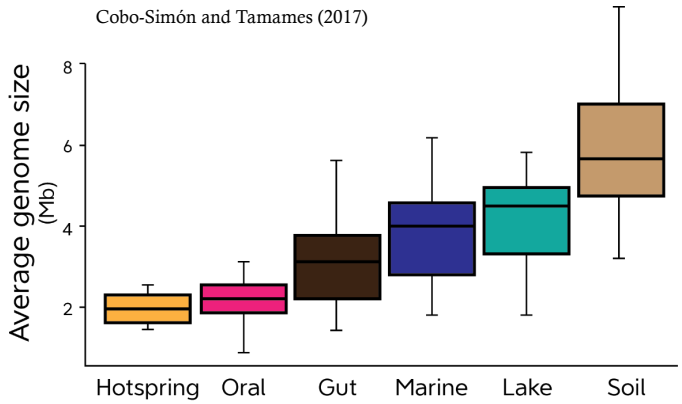


- **Slower growing organisms**

7

7

What makes soil biology unique?



- **Higher biological complexity**
  (more instructions for life)

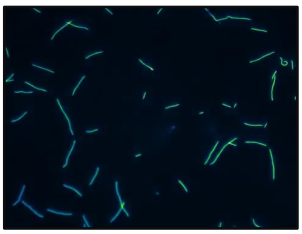
8

8

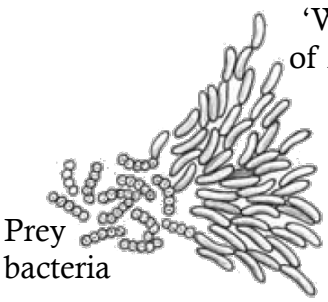
Example of complex behavior

The soil bacterium: *Myxococcus*

1. Specialized surface movement
2. Predatory group behavior
3. Specialized dispersal



gliding motility



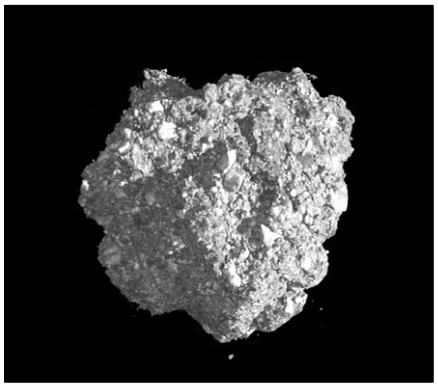
multi-cellular fruiting bodies

9

9

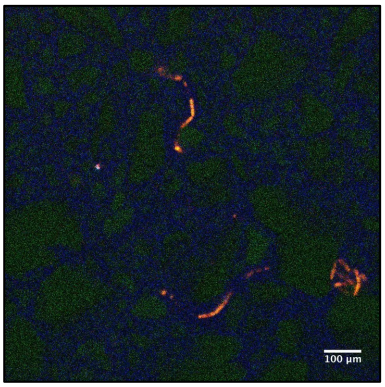
What makes soil biology so diverse?

X-ray Tomography



Waterford Institute of Technology

Transparent soil + fluorescence microscopy



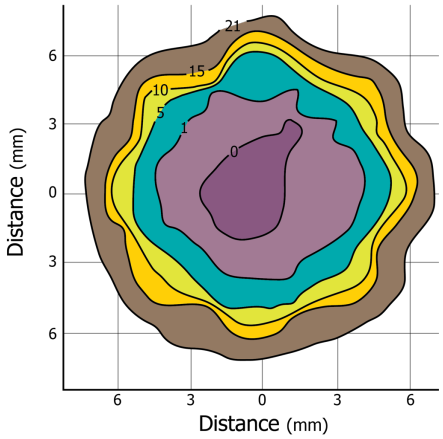
Sharma et al., (2020)

- **Spatial heterogeneity**

10

10

What makes soil biology so diverse?



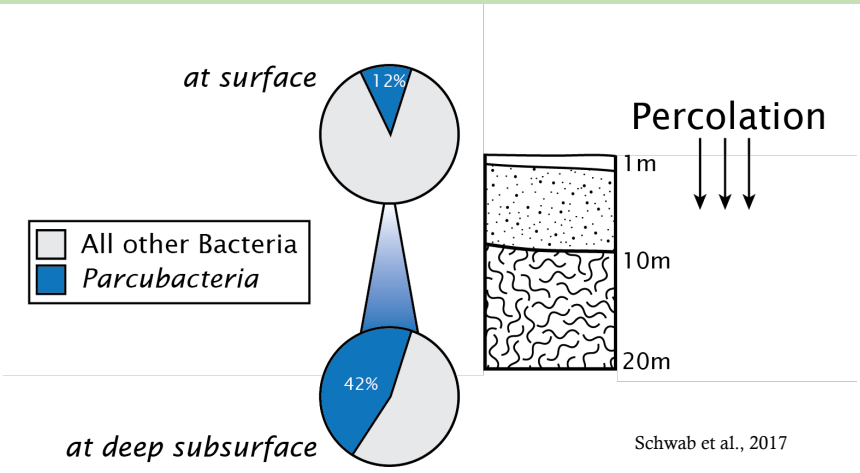
An oxygen gradient in a soil crumb
(macroaggregate)

- **Resource heterogeneity**

11

11

What makes soil biology so diverse?

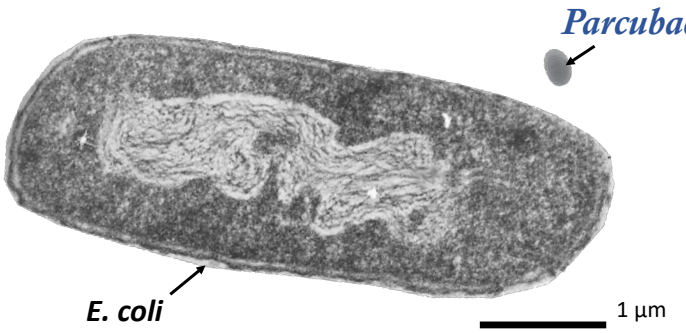


- **Environmental gradients**

12

12

What makes soil biology so diverse?



Parcubacteria

- an 'ultramicrobacteria' discovered in 2017

13

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Summary – Uniqueness of Soil Biology

1. 'Do I contradict myself?'
   - Soil is a heterogenous environment with diverse habitat for multitudes of organisms
2. 'Let your soul stand … before a million universes.'
   - We have a naïve understanding of these multitudes and soil biology is an active topic of research

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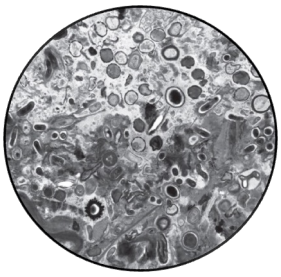
Common questions about managing soil biology and soil health

1. How do soil organisms drive soil health?
2. How do I manage multitudes?
3. Is the conservation of biodiversity part of soil health?

15

1. How do soil organisms drive soil health?

Three Functional Groups of Soil Organisms



Biochemical Transformers

Biological Regulators

Ecosystem Engineers

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Biochemical Transformers

Function	Main groups
• Regulate 90% of energy flow in soil • Build soil organic matter & aggregates • Cycle key macro- and micro-nutrients required by plants	**Soil microbes** (bacteria, fungi, and protozoa)

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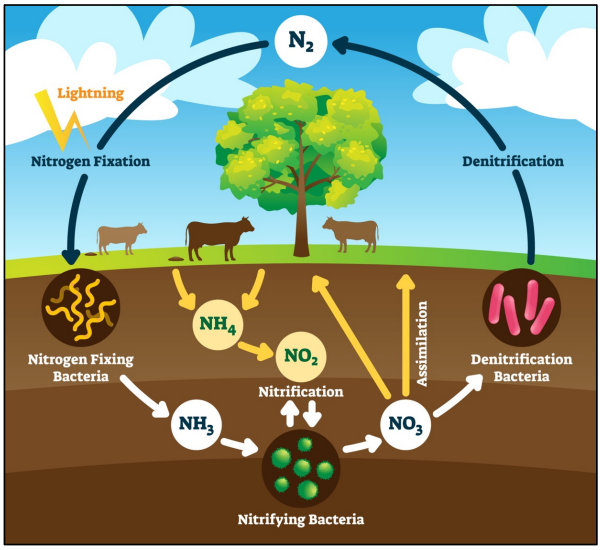
Biochemical Transformers

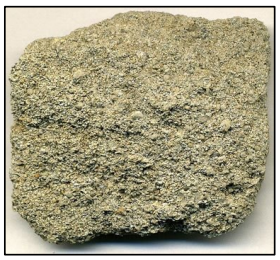
Bacteria govern soil nitrogen cycling



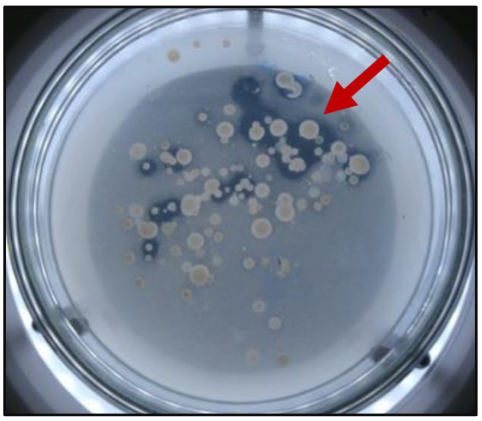
18

Biochemical Transformers

- Plants cannot access phosphorus in minerals
- But, bacteria and fungi can!



Phosphate-rich minerals

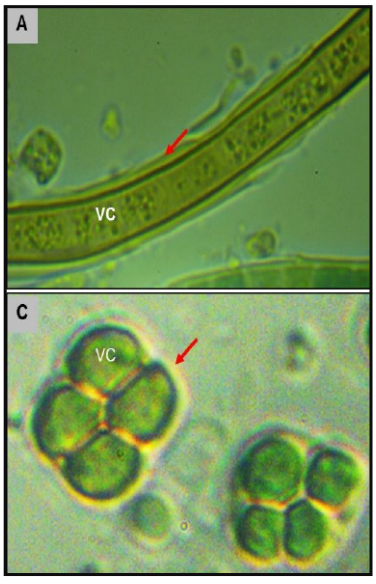


Clearings on Pikovskaya medium reveal the solubilization of calcium phosphate.

19

Biochemical Transformers

- Photosynthetic cyanobacteria and algae add nitrogen to soil and can promote aggregate formation



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Biological Regulators

Function	Main groups
• Control soil populations	**Predators and parasites** small invertebrates, fungi, bacteria, and virus

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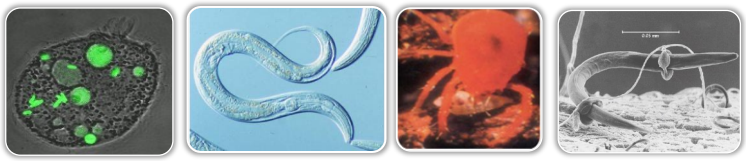
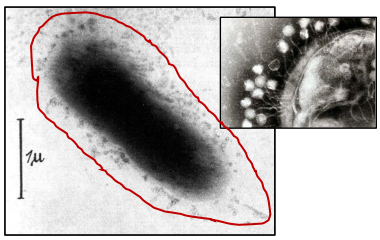
Biological Regulators

- **Predators**: Protozoa, nematodes, springtails, mites



- **Parasites**: Bacteria and virus (primarily bacteriophage)

Bdellovibrio



Bacteriophage ('phage')

22

Ecosystem Engineers

Function	Main groups
• Build pore networks and aggregates • Redistribute nutrients	**Plant roots, earthworms, larger invertebrates, and fungi**

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Ecosystem Engineers

Made by: Wim van Egmond https://vimeo.com/222168889

15-week time lapse

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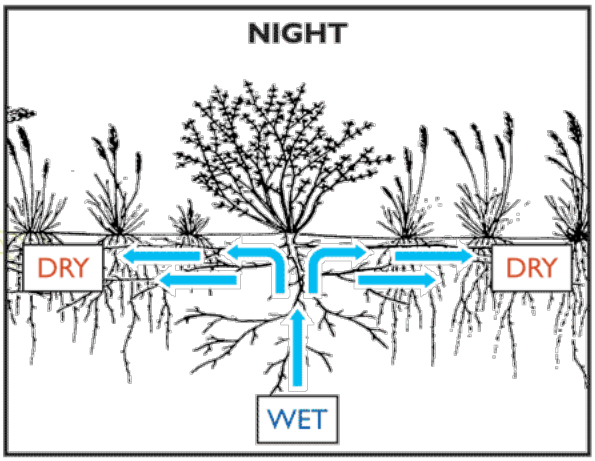
Ecosystem Engineers

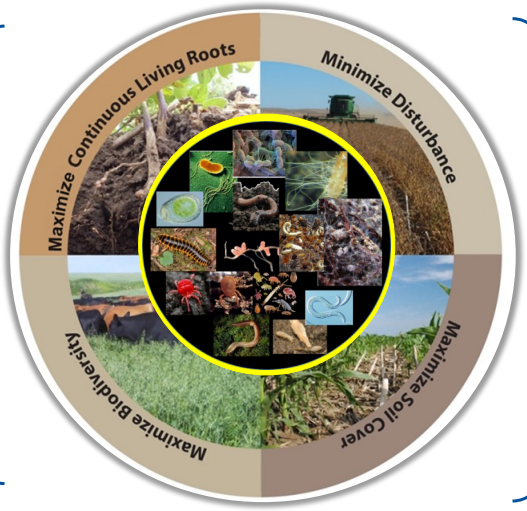


- Plant roots increase the connectivity between pore space – improving gas and moisture transport

25

2. How do I manage multitudes?

Feed Soil Organisms



Protect Soil Organisms

Modified from USDA –NRCS-Principles for High Functioning Soils

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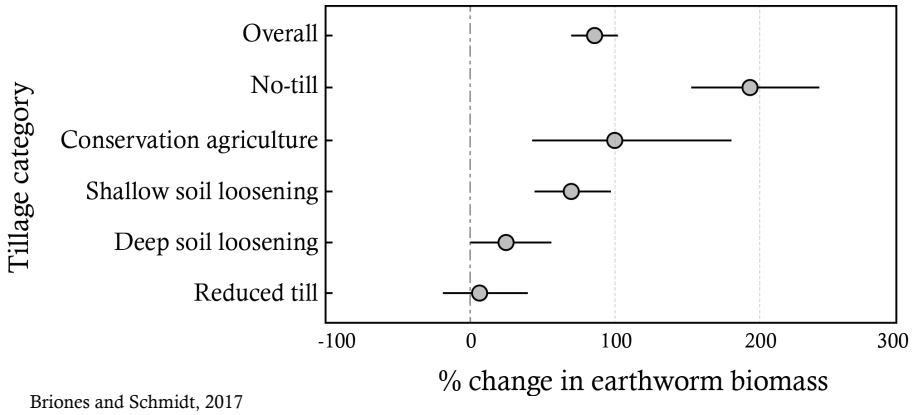
Protect Soil Organisms

- Reduced tillage has a profound impact on soil biology, *particularly ecosystem engineers*



Briones and Schmidt, 2017

27

Biostimulation and Bioaugmentation

There are two key tools to manage soil biological function:

- Biostimulation involves altering soil conditions to favor the growth / activity of native populations.
- Bioaugmentation involves the addition of desired beneficial organisms

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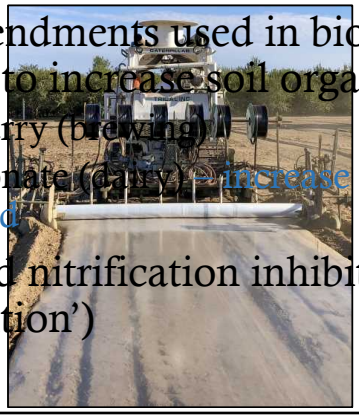
Feed Organisms: Biostimulation

- Biostimulants can be plants or are typically by-products of food industry
  - ex. rice bran and anaerobic disinfestation
- Other amendments used in biostimulation are aimed to increase soil organic matter:
  - Yeast slurry (brewing)
  - Lactobionate (dairy) → increase soil biomass by 70-fold
- Urease and nitrification inhibitors ('bioinhibition')



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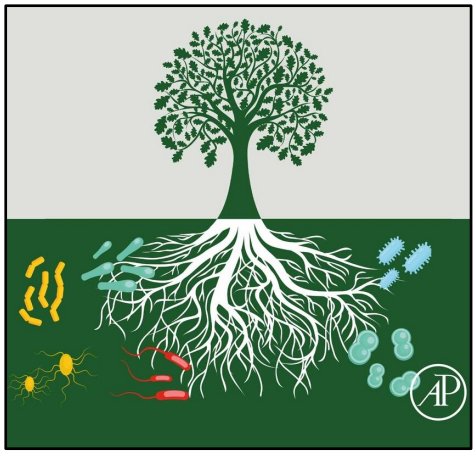
Feed Organisms: The Plant Rhizosphere

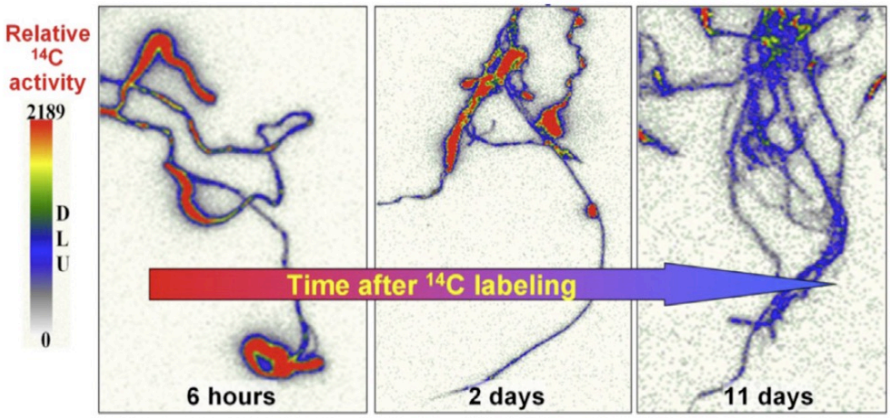
The area surrounding roots supports an active microbial community

- Root exudates
- Root turnover



30

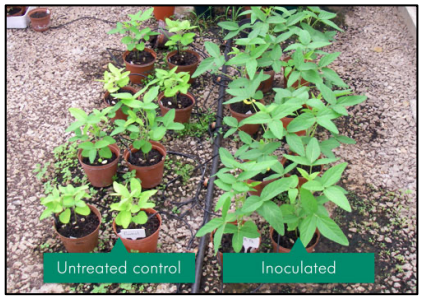
Feed Organisms: The Plant Rhizosphere



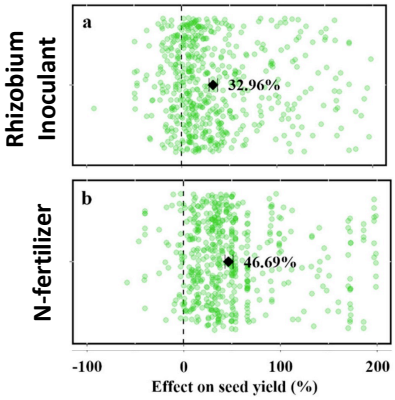
Kuzyakov et al., 2019

31

Bioaugmentation with biochemical transformers



Soybean-*Bradyrhizobium* treatment



Santos Sousa *et al.*, 2022

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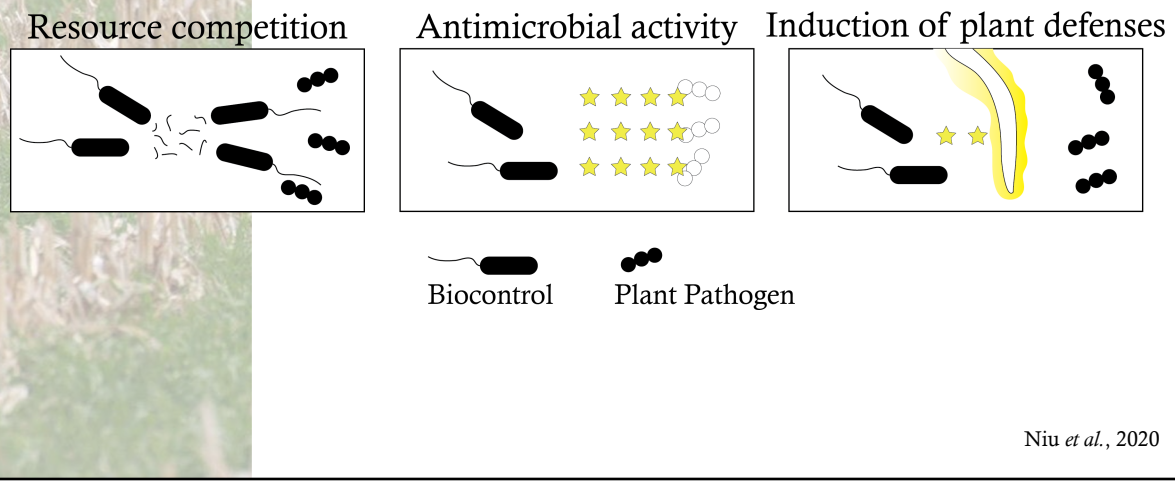
Bioaugmentation with biological regulators: for biocontrol



Niu *et al.*, 2020

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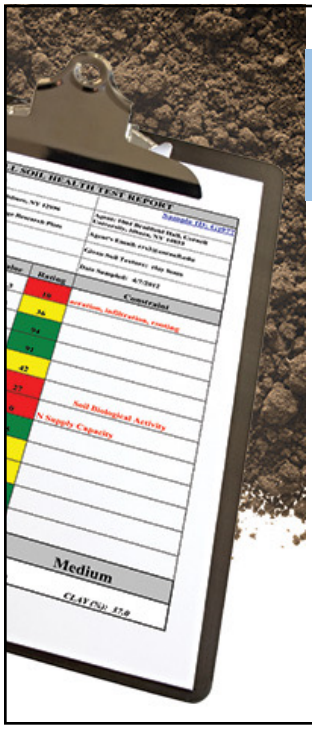
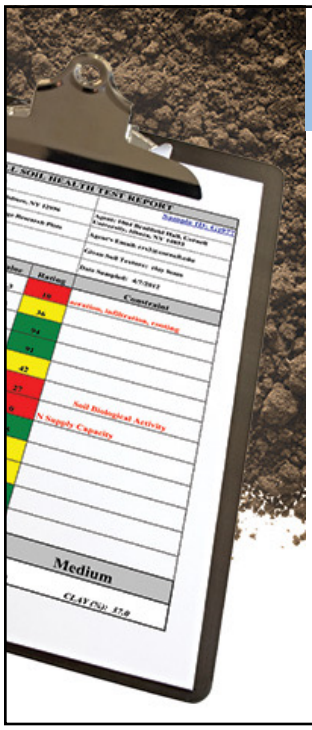


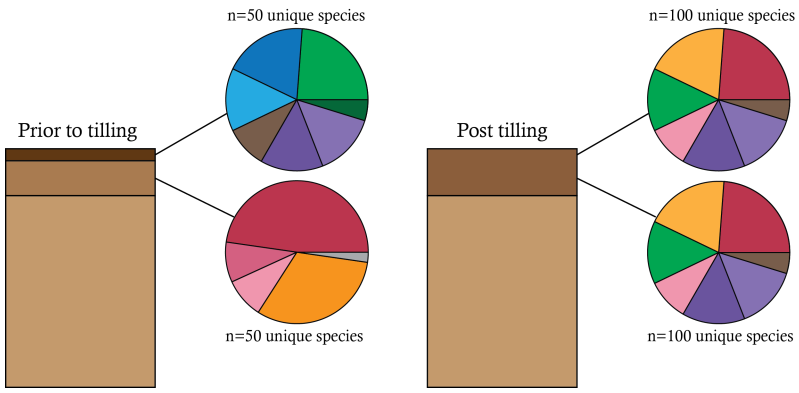
3. Is the conservation of soil biodiversity part of soil health?

No, *not formally anyways*
(at least *not yet*)

34



Biodiversity needs interpretation



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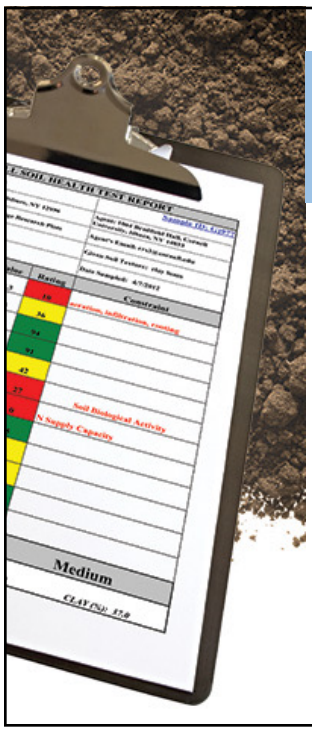

Should we designate soil organisms for conservation?

***Streptomyces*: Still the Biggest Producer of New Natural Secondary Metabolites, a Current Perspective**

by Lavinia Donald [1], Atanas Pipite [1,*], Ramesh Subramani [1], Jeremy Owen [2,3,4], Robert A. Keyzers [3,4,5] and Taitusi Taufa [1]

According to local belief, the soil from a churchyard in Boho can cure infections. A microbiologist who took samples to see if there was any scientific basis for the cure has made an astonishing discovery. **Dr Gerry Quinn found a unique strain of streptomyces, a microorganism used to produce antibiotics.** Dec 29, 2018

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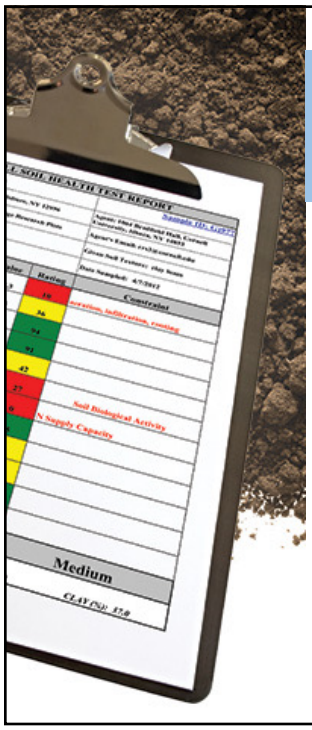

Should we designate soil organisms for conservation?

Should Streptomyces be conserved?

It is important to conserve all species, including Streptomyces, as they play important roles in the ecosystem. Streptomyces are a type of bacteria that are found in soil and are known for their ability to produce a wide range of antibiotics. These antibiotics are used to treat a variety of illnesses in humans and animals. Additionally, Streptomyces are also used in the production of other important chemicals, such as enzymes and pigments.

Conversation with GPT-3 Chatbot

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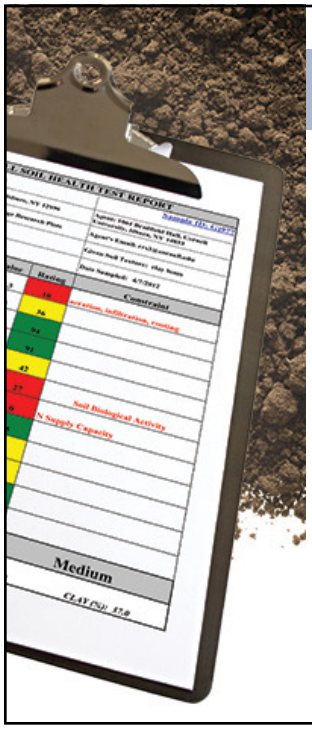
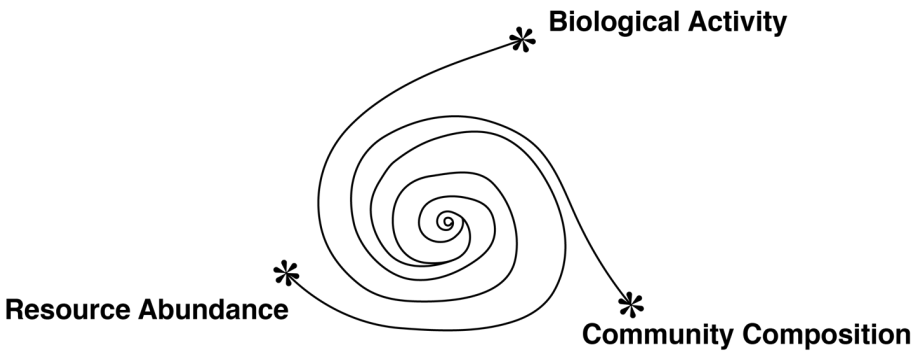


Evaluating Biological Soil Health



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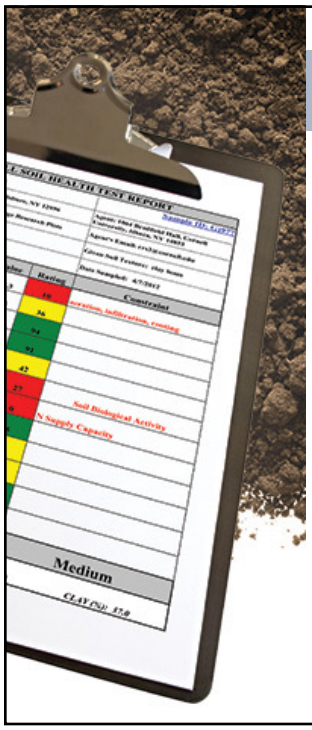
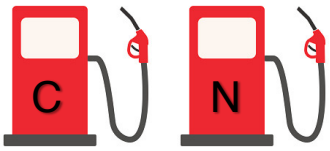
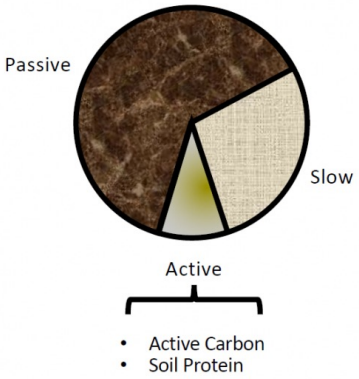


Resource Availability

1. Water-extractable C and N
   - Estimate of bioavailable growth substrates
2. Autoclaved-citrate extractable (ACE) Protein
   - Quality of soil organic N
3. Active carbon
   - Quality of soil organic C





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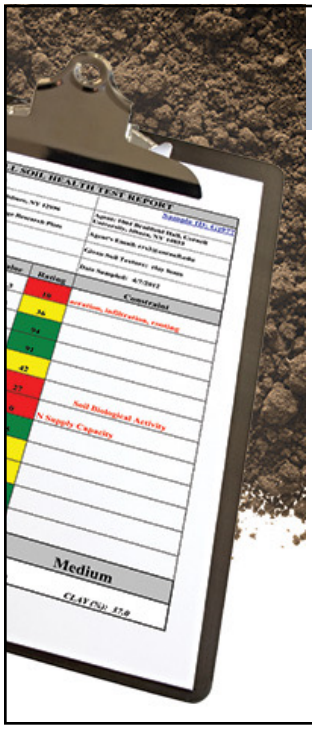
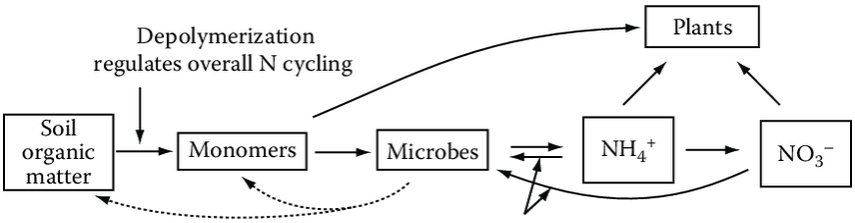


Biological Activity

1. Soil Respiration
   - Bulk microbial activity (function of total C and biomass)
2. N Mineralization Potential
   - Capacity to convert N from organic to inorganic forms



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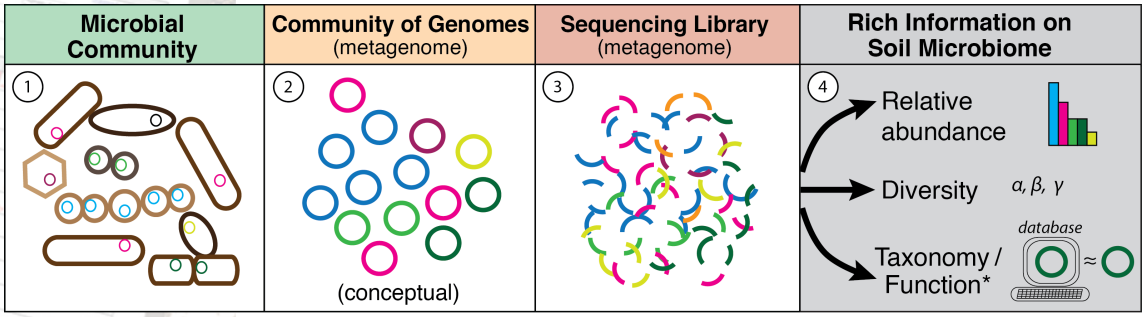
Community Composition



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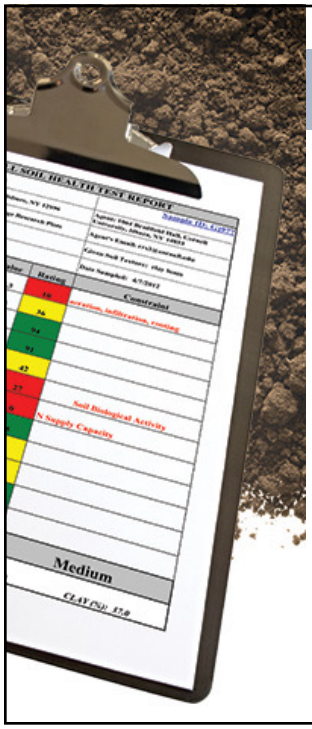
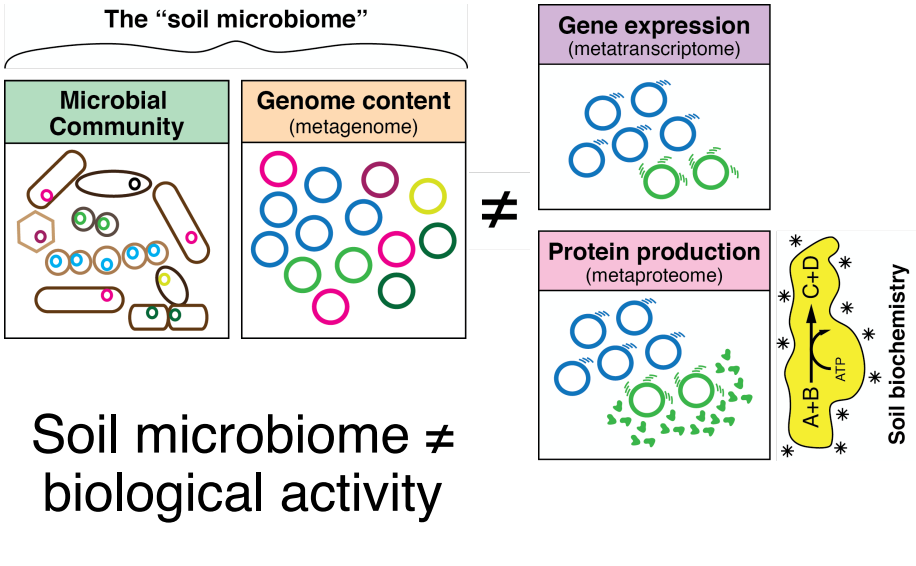


Community Composition



Soil microbiome ≠ biological activity

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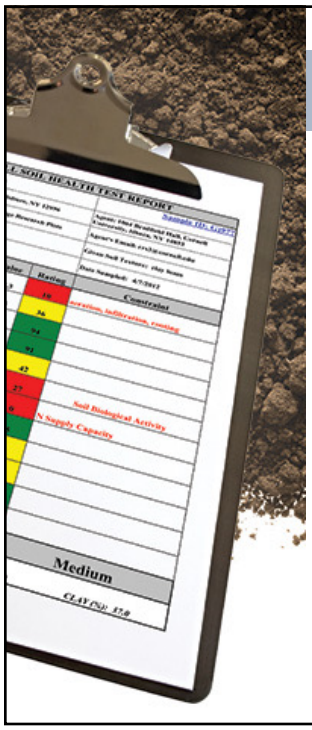
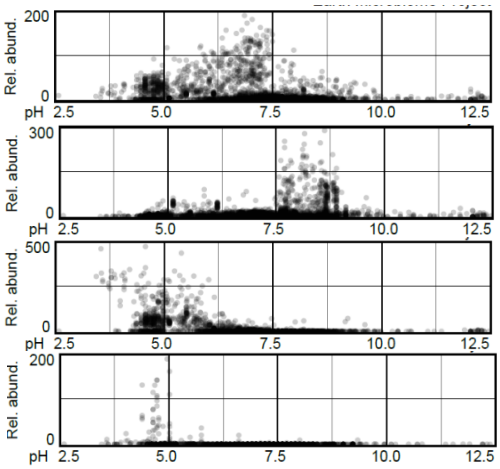


Community Composition

Still, patterns in the microbiome are indicative of soil conditions



Sridhar *et al.*, 2022

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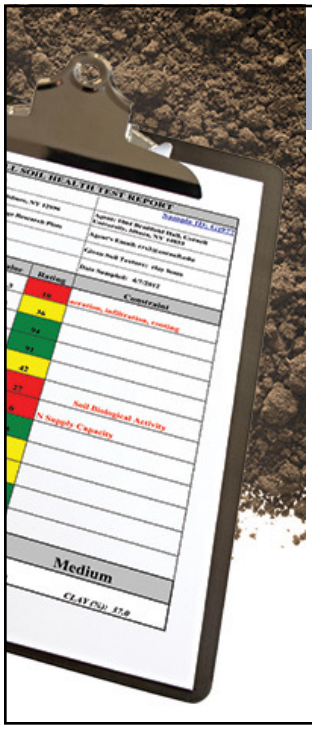
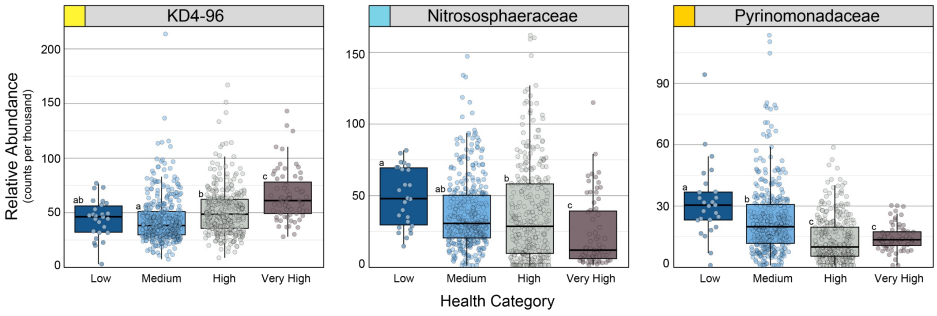


Bioindicators



- *'Nitrososphaera* …are correlated with N-fertilization in agricultural practices in long-term field experiments'
- *'Pyrinomonadaceae*… appear to be characteristic for dry, organic matter depleted soil habitats'

Wilhelm *et al.*, 2022

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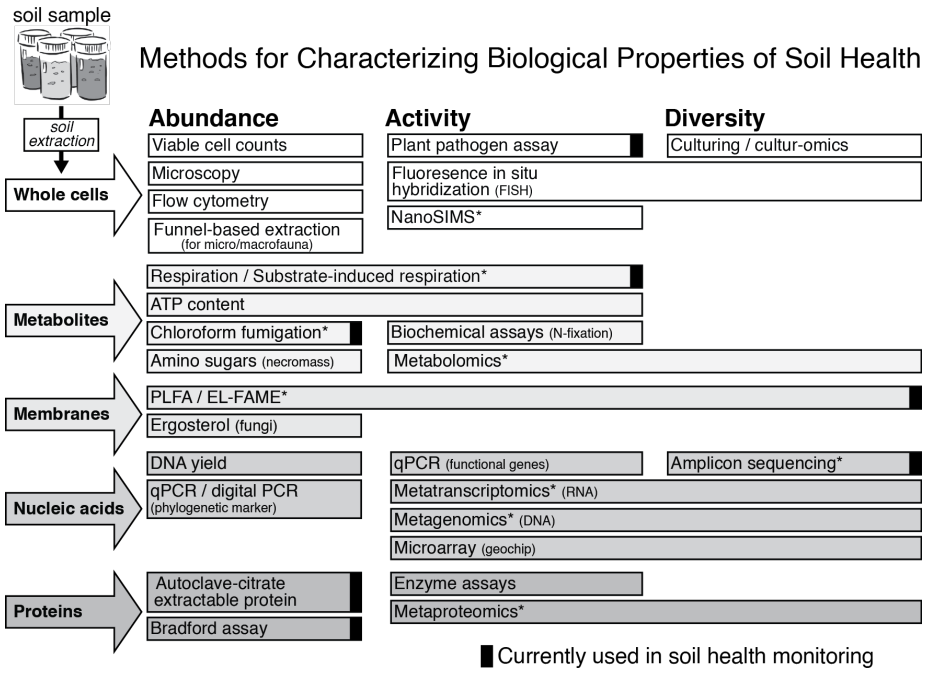

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soil sample
soil extraction
Methods for Characterizing Biological Properties of Soil Health
Abundance
Activity
Diversity
Whole cells
Viable cell counts
Microscopy
Flow cytometry
Funnel-based extraction (for micro/macrofauna)
Plant pathogen assay
Fluoresence in situ hybridization (FISH)
NanoSIMS*
Culturing / cultur-omics
Metabolites
Respiration / Substrate-induced respiration*
ATP content
Chloroform fumigation*
Amino sugars (necromass)
Biochemical assays (N-fixation)
Metabolomics*
Membranes
PLFA / EL-FAME*
Ergosterol (fungi)
Nucleic acids
DNA yield
qPCR / digital PCR (phylogenetic marker)
qPCR (functional genes)
Metatranscriptomics* (RNA)
Metagenomics* (DNA)
Microarray (geochip)
Amplicon sequencing*
Proteins
Autoclave-citrate extractable protein
Bradford assay
Enzyme assays
Metaproteomics*
Currently used in soil health monitoring
* Commonly used with stable isotope probing

Laboratory Methods for Assessing Soil Health

Thies, E., van Es, H. and Wilhelm, R.

In: Biological Approaches to Regenerative and Resilient Soil Systems.

e-mail me: rcwilhelm@purdue.edu

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