Harnessing microbiomes for enhanced agricultural productivity

Gwyn Beattie

IOWA STATE UNIVERSITY
Plant Pathology and Microbiology

American Phytopathological Society

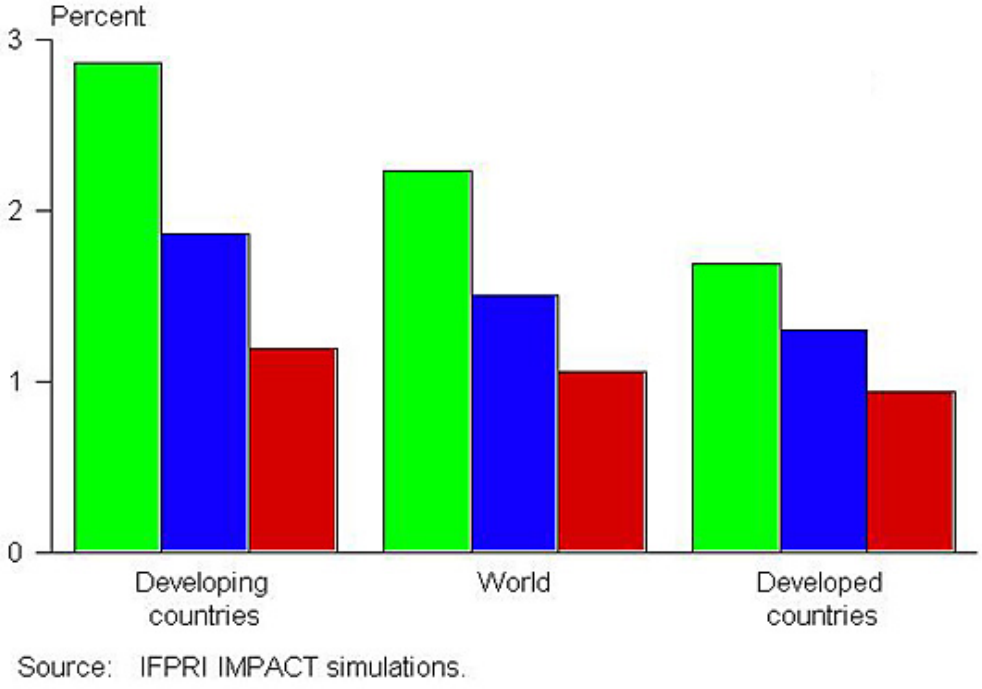
International Alliance for Phytobiomes Research

AGRICULTURAL MICROBIOMES RESEARCH COORDINATION NETWORK


Global Grand Challenge
To sustainably feed the world .....

How do we reverse the current *decrease* in annual yield growth?

Annual growth in cereal yields



Source: IFPRI IMPACT simulations.

1967-1982

1982-1994

1993-2020

Need ~2.4% increase per year to feed the global population in 2050

Plant-based Agriculture: A complex system

Plants

Climate

Micro- and Macroorganisms

Viruses
Archaea
Bacteria
Amoeba
Oomycetes
Fungi
Algae
Nematodes

Arthropods, Other Animals and Plants

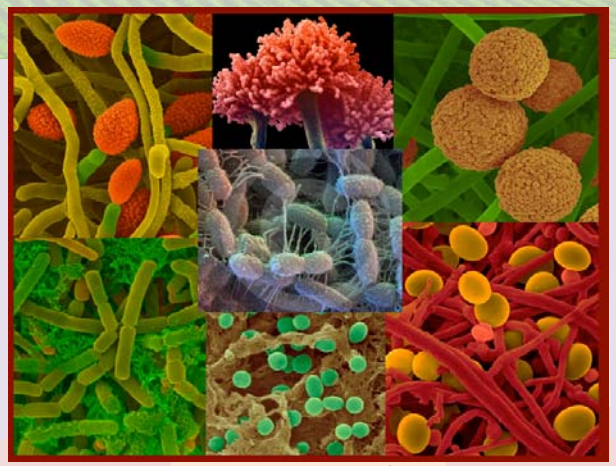
Insects
Arachnids
Myriapods
Worms
Birds
Rodents
Ruminants
Weeds

Their environment

Soils

Associated organisms

Roots recruit a myriad of microbes



piremongolia.files.wordpress.com

Enhance uptake of nutrients and water

N_2 fixation
P solubilization

Enhance tolerance to environmental stresses

Drought, Salinity
Heat/Cold,
Heavy metals,…

Activate defenses against pests & pathogens

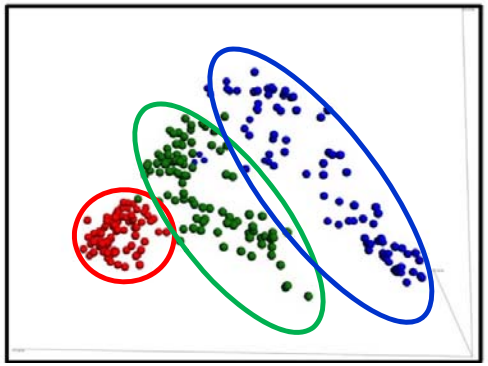
Increase plant health & productivity

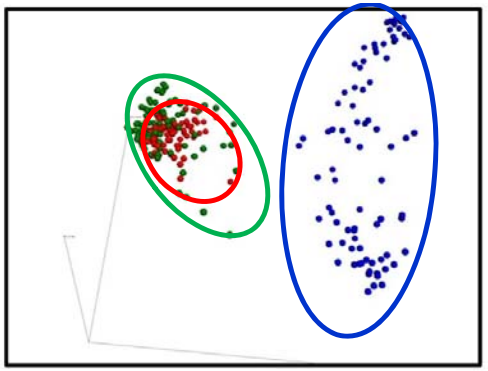
Promote plant growth

Root recruitment promotes clear community shifts

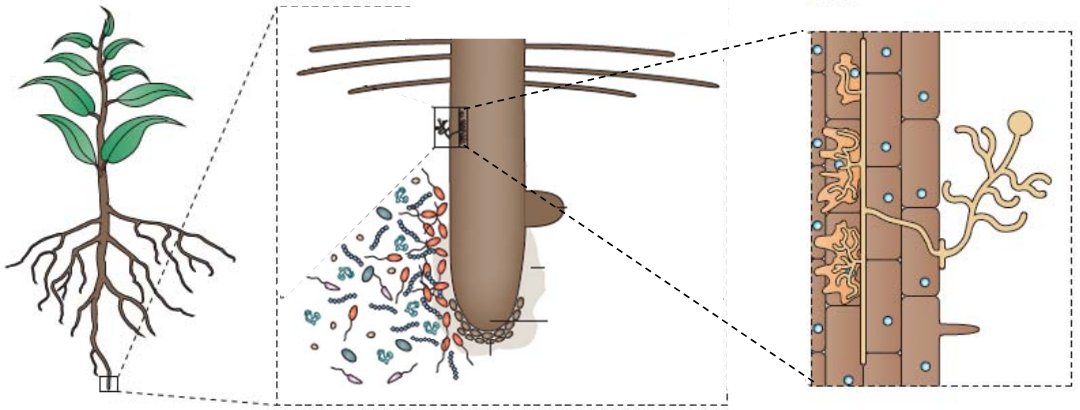
Bacterial Communities **Fungal Communities**

Soil
Rhizosphere
Endosphere





Soil =
Microbial seed
bank



Phillipot. 2013. *Nature Reviews Microbiology*

What are the primary factors driving microbiome assembly?

Abiotic factors

Soil properties

pH texture organic content

Climate

Temperature Water availability

Biotic factors

Microbe source seed, soil, air

Plant properties species genotype age Plant community diversity

Macroorganisms

Protists, nematodes, aphids

→ **Identify microbial indicators/predictors of crop and soil health**

→ **Maximize the influence of seed microbiome manipulation on plant fitness and productivity**

Can we improve plant-microbiome benefits through breeding?

- **Has domestication altered crop mutualisms?**
- **Has breeding under ideal plant growth conditions reduced the recruitment of beneficial microbes?**

Example: Can we use knowledge of microbiomes to enhance drought tolerance?

Drought

(Photo: Joseph Murphy/Iowa Soybean Association)

Soil water content influences community composition

Bacterial Communities **Fungal Communities**

Proximity to the root

Soil

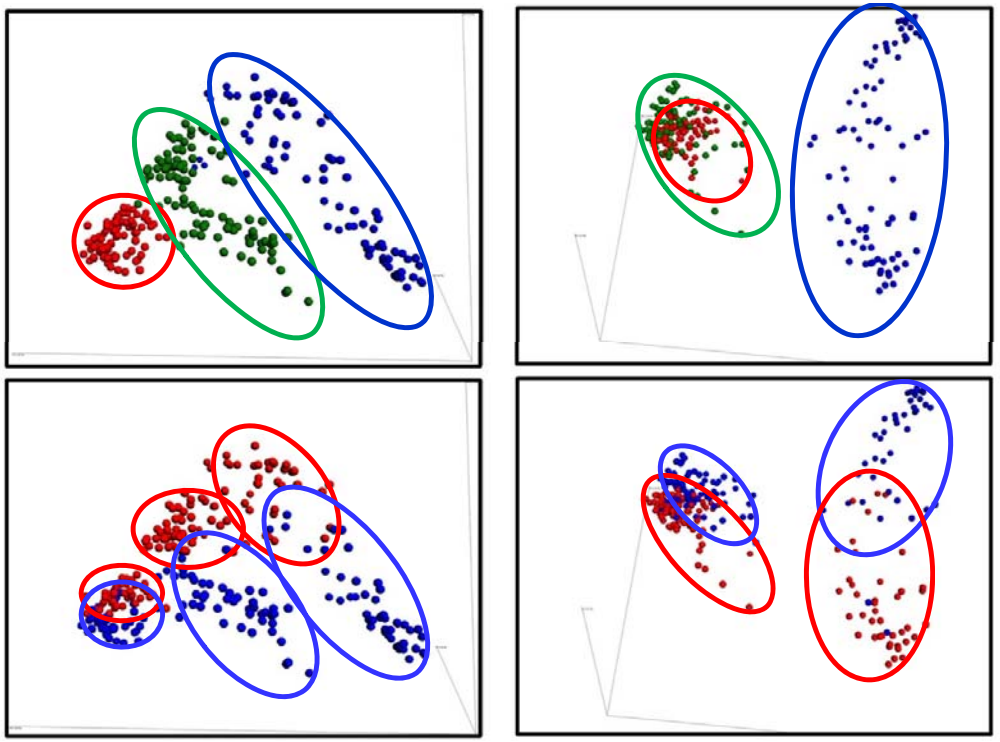
Rhizosphere

Endosphere

Soil water content

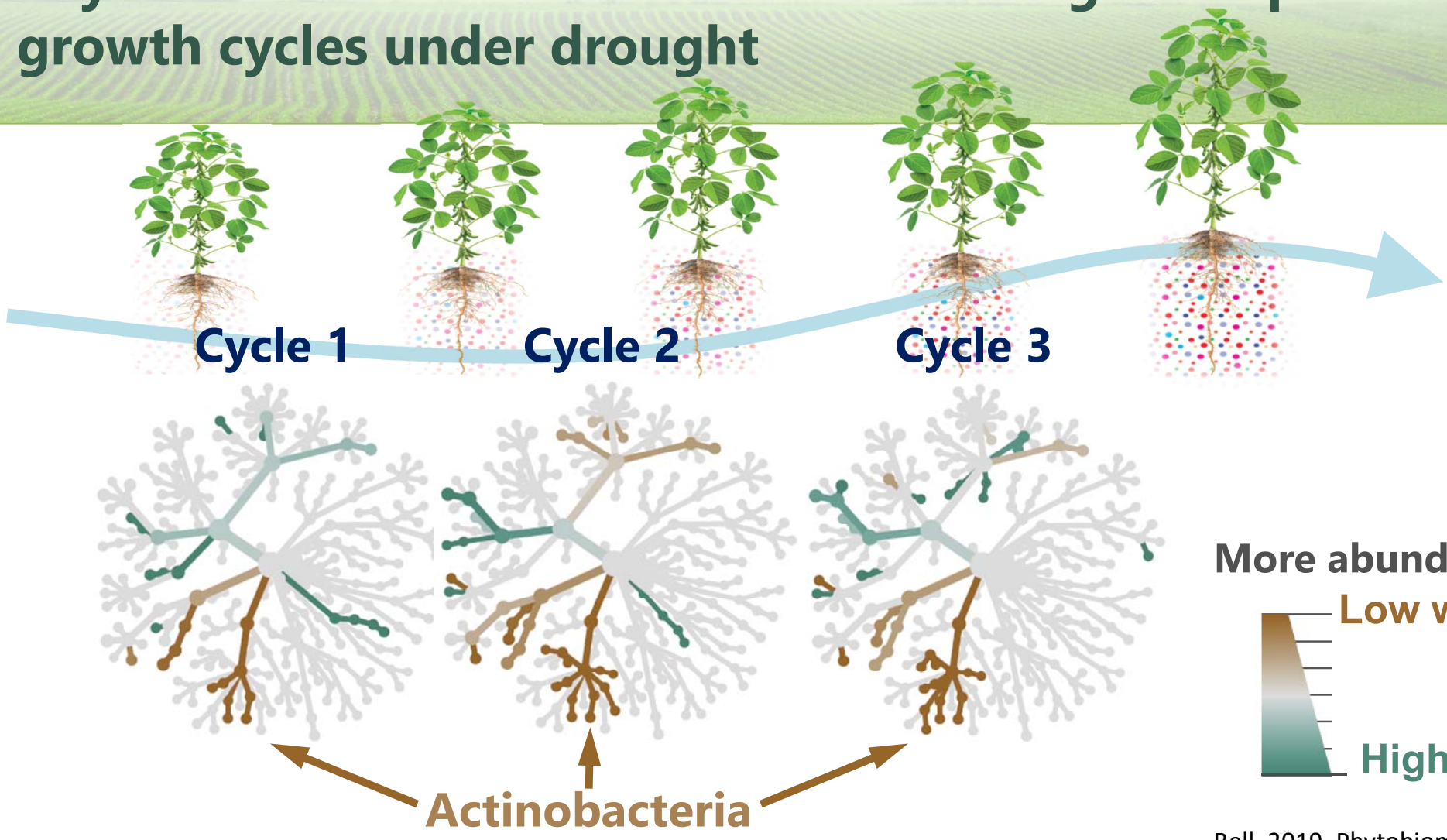
Low

High



PCoA plots

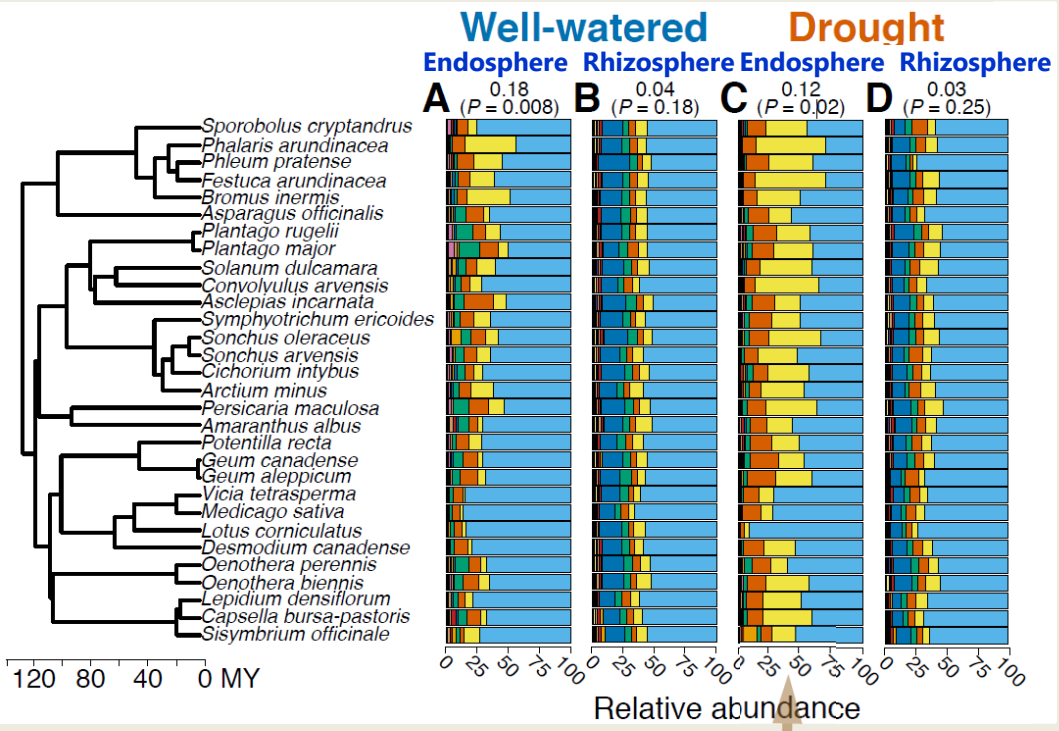
Soybeans enrich for Actinobacteria during serial plant growth cycles under drought



Bell. 2019. Phytobiomes J. 3:3-21

Many plant species enrich for Actinobacteria under drought

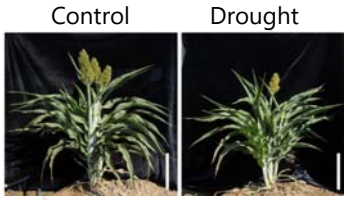
>30 diverse plant species



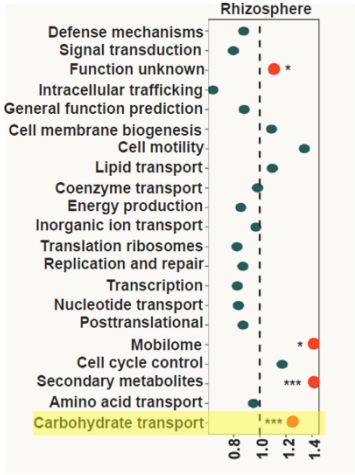
Actinobacteria

Fitzpatrick. 2018. PNAS 115:e1157

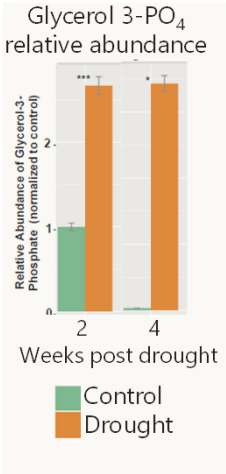
Sorghum



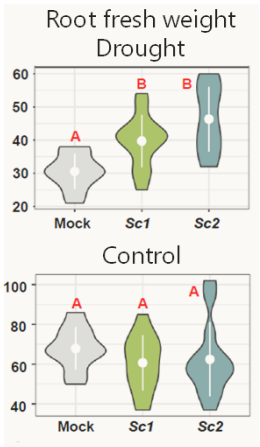
Metatranscriptomics



Metabolomics



Isolates



Xu. 2018. PNAS 115:e4284

- **Can we breed/engineer plants to better recruit beneficial microbes/microbiomes?**

- **Can we breed microbes/design biologicals to enhance their benefits to host plants?**

What are the mechanisms by which specific management practices promote ecosystem health?

Plant diversity

Monoculture
Cover crops
Crop rotations
Intercropping

Inputs

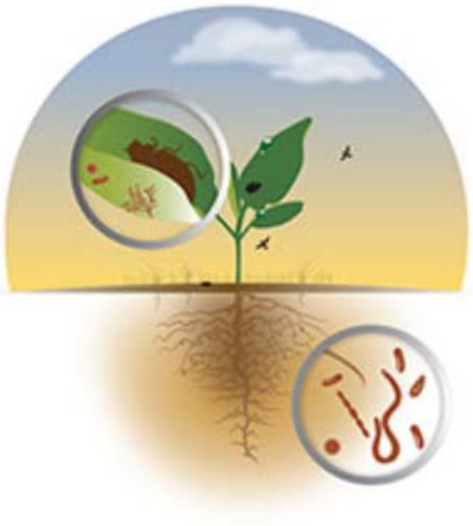
Organic/Inorganic N
Fertilizer rate, timing
Herbicides/Pesticides

Cultural practices

Till/No-till
Plant time
Irrigation/Drainage
Livestock mgt

→ Design novel or improved management practices

Fundamental understanding of plant microbiomes



- How do plant exudates/bacteriophage/ nematodes/protists affect the ecology/evolution/ function/development of plant microbiomes?
- How do microbes/microbiomes prime the plant immune system against pests and pathogens?
- How do microbe-microbe and microbe-plant-insect interactions influence
  microbiome diversity, function and resilience?
  microbiome impact on nutrient cycling and C sequestration?

Common study systems

Model plant species

Arabidopsis thaliana

Medicago truncatula

Populus trichocarpa

Brachypodium distachyon

Major crop species

Maize

Soybean

Wheat/Barley

Rice

Challenges in plant microbiome studies

- Large number of plant species (~7,000 cultivated crop species)* and varieties (cultivars, landraces, elite varieties) of each
- Extensive permutations of Plant genotype x Environment x Management x Microbiome interactions → affect repeatability, generalizability and experimental sampling
- Wide diversity of spatial scales (µm → field → region → planet) and temporal scales
- High environmental heterogeneity

*Khoshbakht. 2008. Genet Resour Crop Evol 55:925

Technology needs

- Approaches to separate microbial metagenomes/ metatranscriptomes from host DNA/RNA
- Improved taxonomic identification and databases that allow for the integration of distinct information
- Whole genome-based identification and associated impacts on plants, animals and the environment for risk assessment and permits

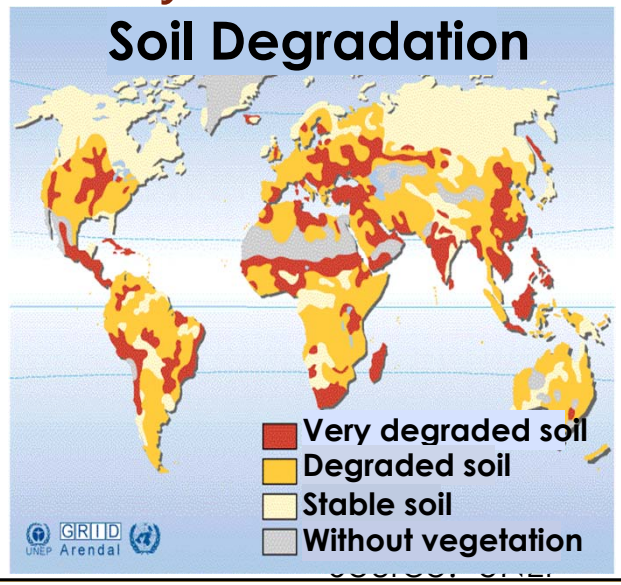
Opportunities presented by plant microbiome studies

- Experimental control, sample accessibility, high sample numbers
- Availability of long-term sites with known historical management
- Opportunities for comparisons such as evolutionary (e.g., pre- vs post-domestication) and ecosystem (agriculture vs. natural)
- Short path to translate fundamental findings into application
- Strong infrastructure for dissemination of applications & opportunities to engage farmers

Broad relevance of plant microbiome studies

- Sustainable crop production for food, feed and fiber (bioenergy)
- Environmental health (phytoremediation, forest health)
- Human health (human pathogens on plants, digestibility)
- Climate change mitigation
  (N cycling impacts, C sequestration)
- Rehabilitating degraded and depleted lands

*1.5 billion people depend on degraded lands for survival!



Funding & Organizations

Primary US funding

$$$ $$$ $$$

USDA
NSF
DOE
Commodity groups
Private industry
Nonprofit foundations
(FFAR, Noble)

AGRICULTURAL MICROBIOMES RESEARCH COORDINATION NETWORK

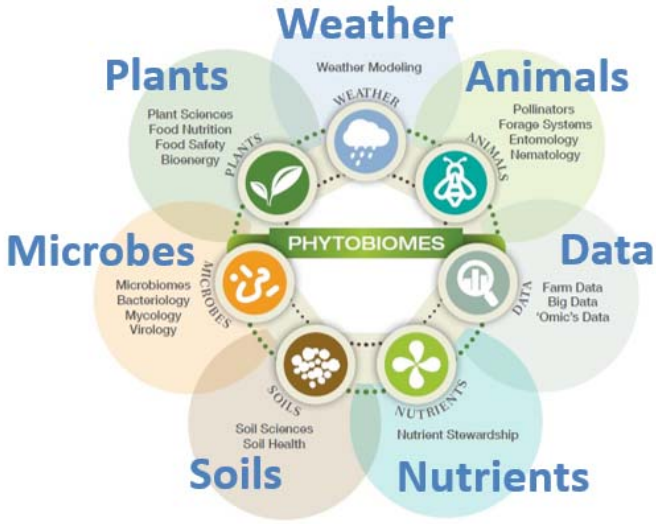
APS

American Phytopathological Society

American Society for Agronomy
Crop Science Society of America
Soil Science Society of America
American Society of Plant Biologists

PHYTOBIOMES ALLIANCE

International Alliance for Phytobiomes Research



Private sector companies (agricultural biologics, seeds, crop protection chemicals)

International Alliance for Phytobiomes Research Sponsors