MANAGING SOIL AND PLANT MICROBIOMES FOR BETTER CROP AND HUMAN HEALTH

Lori Hoagland, PhD

Professor of Soil and Crop Microbial Ecology

Dept. of Horticulture and Landscape Architecture

Purdue University

OUTLINE

- What is a microbiome and why should we care?
- What factors are most critical in shaping microbiomes and the services they provide?
- Examples of what we've learned in my lab about how to manage root microbiomes and the implications of these microbiomes on crop health, quality and safety.
- Questions

MICROBIOMES

WHAT IS A MICROBIOME?

- **Definition:** the community of microorganisms that can usually be found living together in any given habitat

Functions include:

- Aiding digestion
- Supporting our immune systems
- Producing essential vitamins
- Protection against pathogens
- Positively impacts mental health

SOIL MICROBIOMES

Functions include:

- Nutrient cycling & uptake
- Soil aggregation
- Water retention & uptake
- Pathogen suppression
- Pollutant sequestration and detoxification
- *Support our mental health*

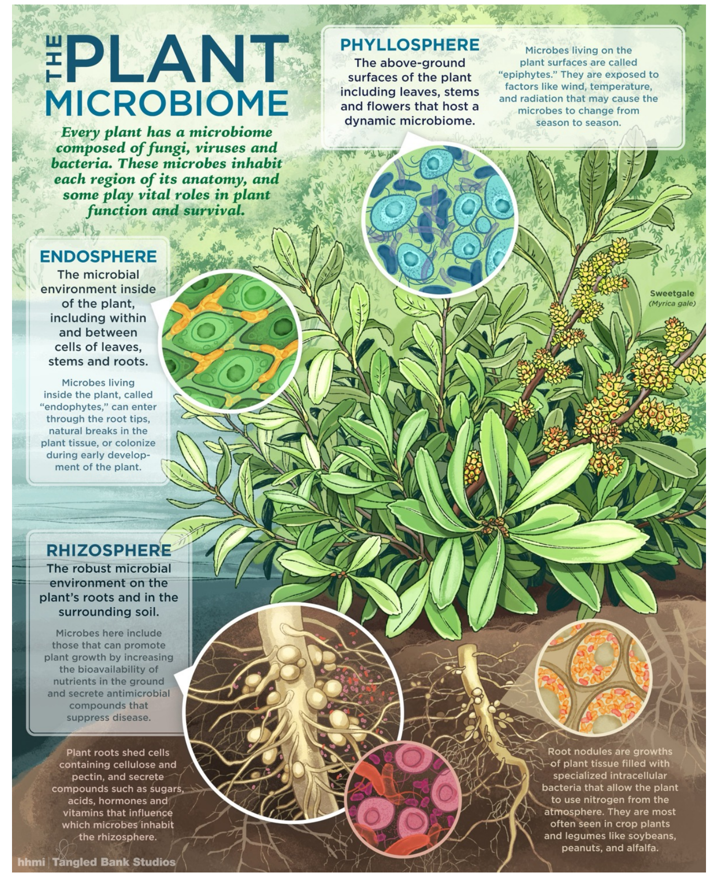
Image: Cooper, 2018

https://mother-nature.ca/the-mental-health-benefits-of-gardening/

The most abundant and diverse microbial habitat on the planet

PLANT MICROBIOMES

- Plants are literally covered, inside and out with microorganisms
  - -> *phyllosphere* (*leaf/stem/fruit surfaces*)
  - -> *rhizosphere* (*on the surface of roots*)
  - -> *endosphere* (*inside the plant*)
- More microbes than plants (*total # of microbial cells actually outnumbers those of the plant*)
- ***What are these microbes doing?***

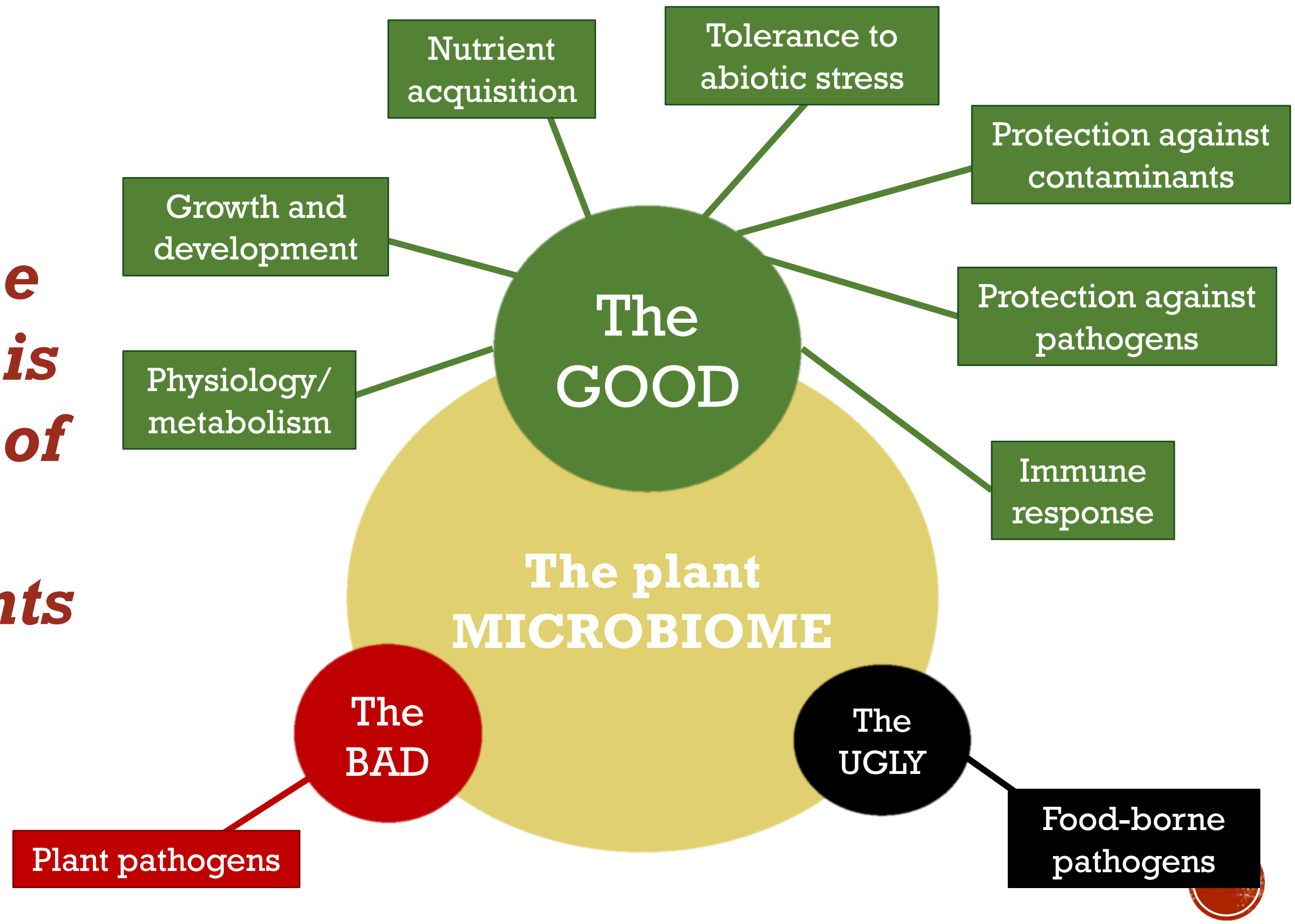


https://imgur.com/gallery/dGmS3qy

The Good, The Bad, and The Ugly

(modified from Mendes et al., 2013)

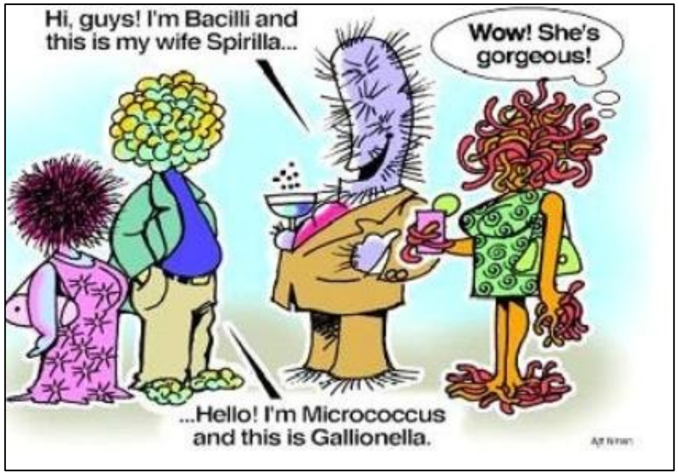
Composition of the plant microbiome is a key determinant of the health and productivity of plants



CRITICAL FACTORS LIKELY TO PLAY A KEY ROLE IN SUPPORTING BENEFICIAL PLANT MICROBIOMES

MICROBIAL PRODUCTS

- Beneficial microbes isolated from soil and plant tissues with strong functional traits
- Microbes that were developed in the lab to produce strong functional traits (ie. *Trichoderma harzianum* T22)
- Efficacy in promoting plant growth and other functions such as pathogen suppression can be very dramatic under controlled conditions
- ***HOWEVER***, *<u>efficacy in the field is often highly variable and inconsistent</u>*



Are there other ways to support healthy crop microbiomes and perhaps enhance the efficacy of these types of products?

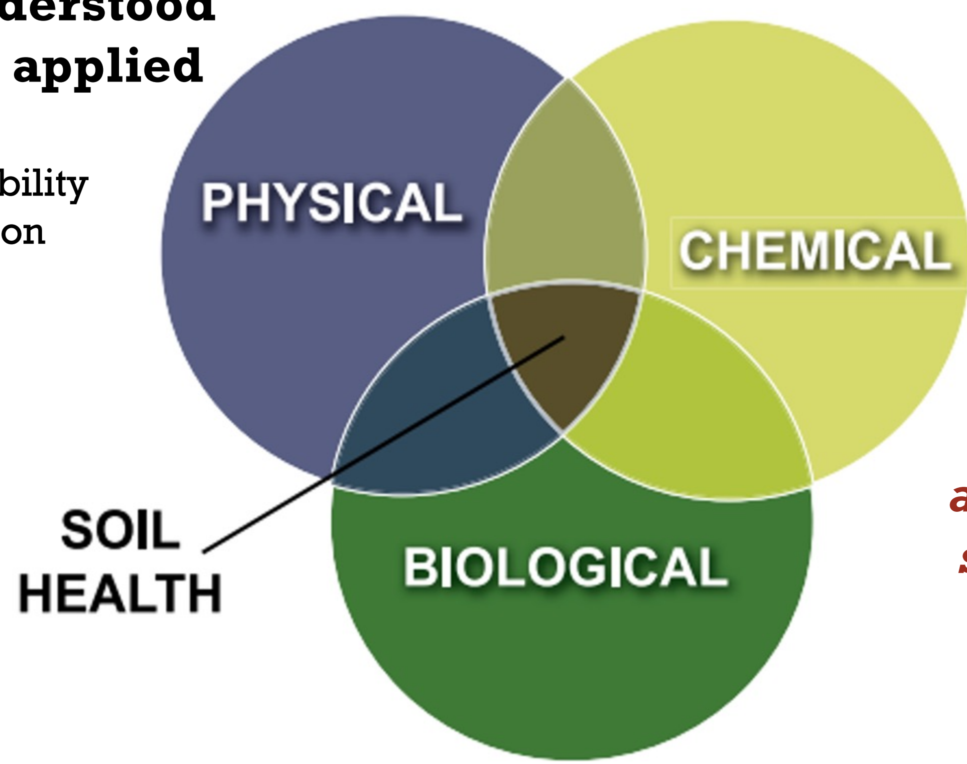
MOST PLANT MICROBIOMES ARE RECRUITED FROM BULK SOIL

Soil health provides the foundation for sustainable agricultural production systems

QUANTIFYING SOIL HEALTH

Fairly well understood but less often applied

- Bulk density
- Aggregate stability
- Water infiltration



Well understood and most often applied

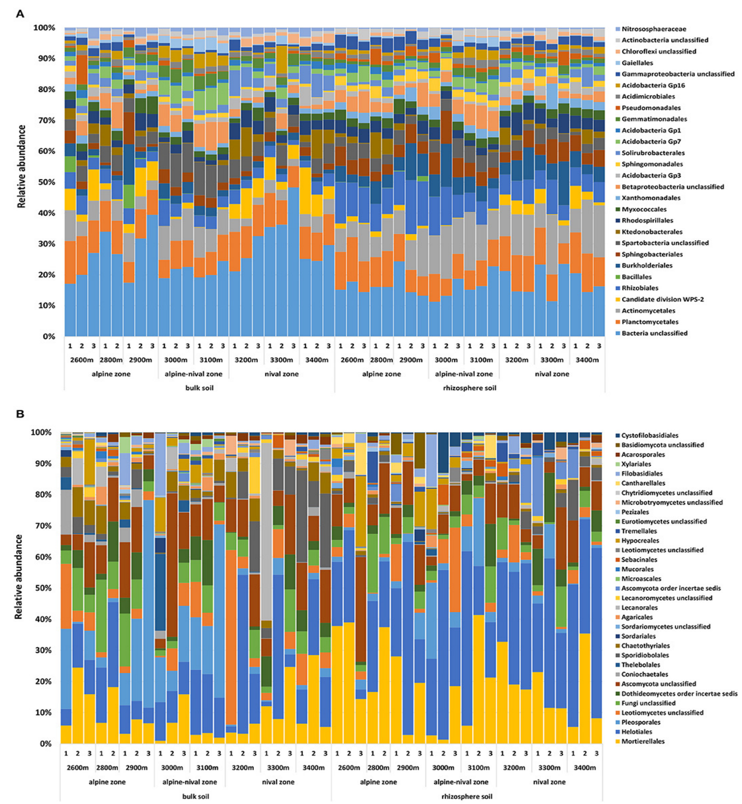
- Soil pH
- Cation exchange capacity (CEC)
- Available mineral nutrients
- Electrical conductivity (EC)

Least understood and applied due to difficulty in studying and quantifying, yet highly important!

- Microbial activity
- Microbial community composition

CHALLENGES ASSOCIATED WITH STUDYING SOIL MICROBIOMES

- Soil microbiomes are incredibly diverse
  - *- in 1 g of soil there can be over 1 million species of bacteria + fungi and archaea!*
- The identify and functional capacity of many soil microbial species are still unclear
- Many species likely work together in consortiums to carry out critical functions
- Soil microbiomes are highly heterogeneous
- ***We still have a lot to learn!***



Examples of what a microbiome can look like

ROOT MICROBIOMES

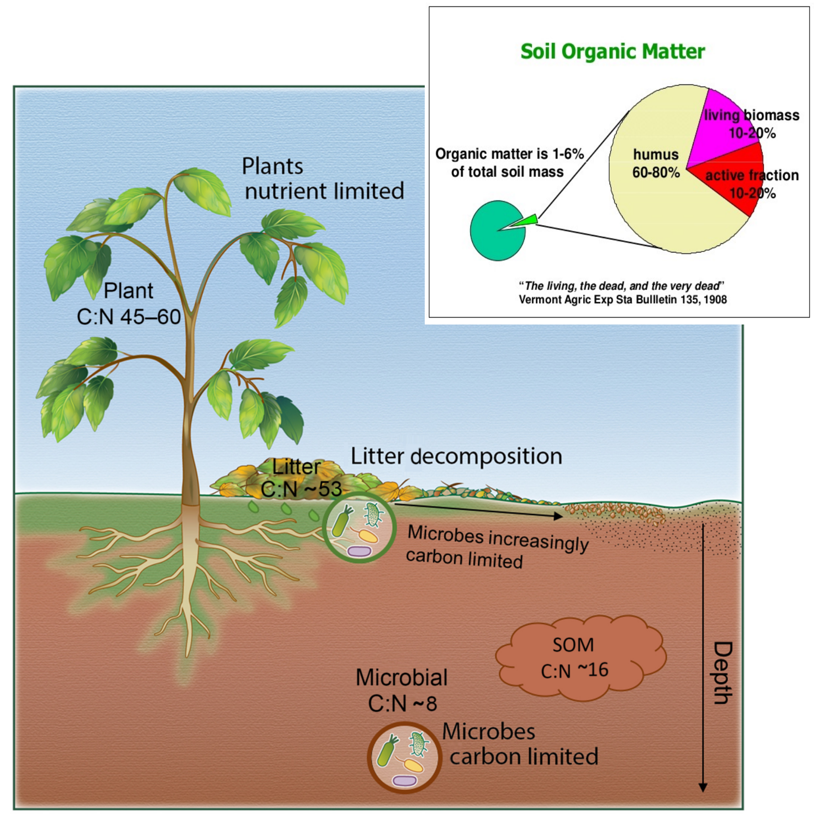
Opportunity to better understand connections between soil and plant health

- Dynamic community of microorganisms living on the surface or inside plant roots
- Can positively or negatively affect plant health via a range of processes
- Are generally much more specialized than microbes residing in bulk soil
- While most root microbiomes are recruited from bulk soil, plants can also alter the composition of soil microbes via root exudates and other processes (*cries for help* and *plant-soil feedbacks*)

WHAT CAN WE DO TO SUPPORT BENEFICIAL SOIL AND ROOT MICROBIOMES?

Provide labile or active sources of carbon

- Unlike plants, soil microbes are carbon-limited
- Microbes can obtain carbon from plant roots (exudates) and organic matter, but not soil organic matter is available to all microbes
- Any time you start cultivating soil, you will deplete active soil carbon
- Soil carbon must be replenished to improve and retain soil health



Soong et al., 2019

- ***How can labile pools of soil carbon be restored?***

COVER CROPS

- Non-cash crops grown for the protection & enrichment of soil
- Most cost-effective way to restore soil organic matter and improve soil health
- Root exudates and crop residuals provide labile organic carbon compounds required to support soil microbiomes
- Also create pores for aeration and water storage that can support beneficial soil organisms

(E. Brennan)

EXAMPLE #1

Leguminous cover crop supply nutrients, improve soil health, alter root microbiomes and reduce susceptibility to soilborne pathogens

(Rudisill et al., 2015 *HortScience*)
(Rudisill et al., 2016 *Applied Soil Ecology*)

HIGH TUNNELS (OR POLYHOUSES)

- **Potential benefits:**
  - season extension
  - protection from some pests
  - increase yield
- **Potential drawbacks:**
  - ***soil quality degradation***
    - intensively managed (*loss of SOM*)
    - high evapotranspiration/limited leaching (*issues with salinity*)
  - ***build up of soil-borne pathogens***
    - limited crop rotation

PHASE I

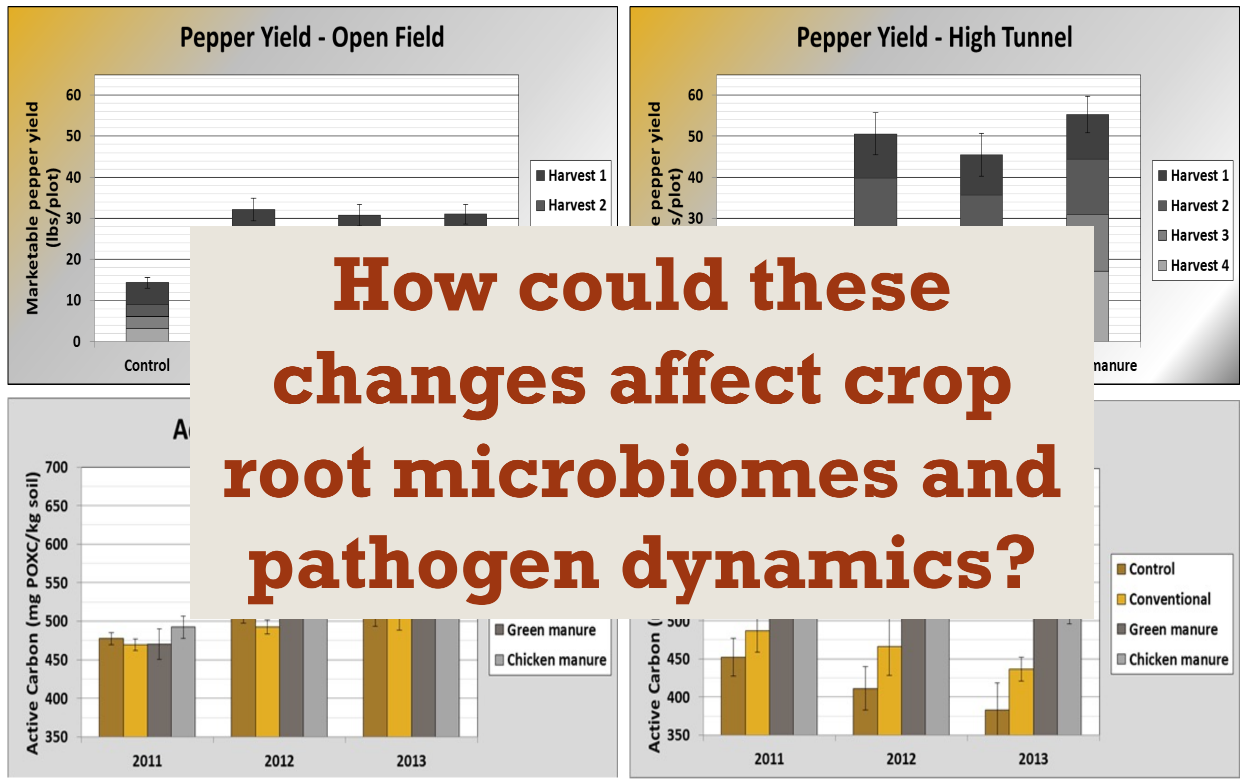
Can a green manure crop help supplement fertility needs in high tunnels while improving rather than depleting soil health?

❖Research design (2011-2013)

- Treatments (repeated annually):
    1) unamended control
    2) inorganic (urea)
    3) chicken litter compost (industry standard)
    4) green manure (*hairy vetch* + *alfalfa pellets*)
- RCBD w/ 4 replicates
- High tunnel and open-field
- Pepper *(rather than tomato)* planted annually

IMPACTS ON SOIL AND CROP HEALTH

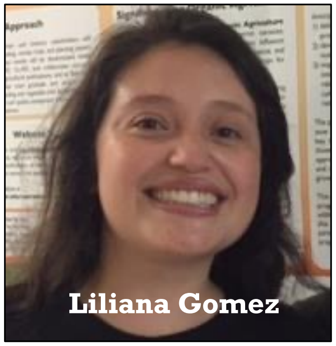
- Pepper yield greater in high tunnels
- All fertility treatments met plant nutrient needs
- Soil health declined in high tunnel conventional fertility treatment
- Soil health improved by green and chicken manure & microbes were more efficient at cycling carbon and nitrogen



Rudisill et al., 2015 *HortScience*   Rudisill et al., 2016 *Applied Soil Ecology*

PHASE II

***Objective*: determine how changes in soil health could affect susceptibility to soilborne pathogens and investigate potential mechanisms**

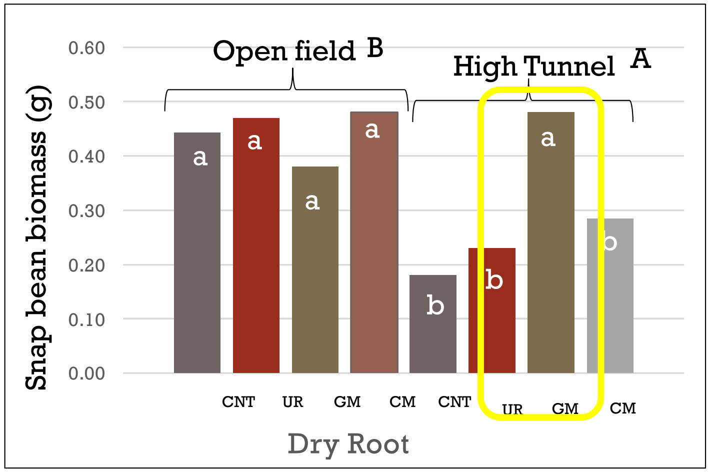


- Design:
  - soil collected from field trials pasteurized or left untreated, amended with ***Rhizoctonia solani*** and planted with susceptible snap bean variety
  - RCBD with six replicates

IMPACTS ON SUSCEPTIBILITY TO *R. SOLANI*

- Soils collected from the high tunnel were more susceptible to *R. solani* than from the open field
- The HT green manure treatment was less susceptible to *R. solani* than the other treatments
- No difference between treatments and systems when soil was pasteurized (***the effects were microbially-mediated***)

Rhizosphere soil collected for shotgun metagenomics and metranscriptomic assays

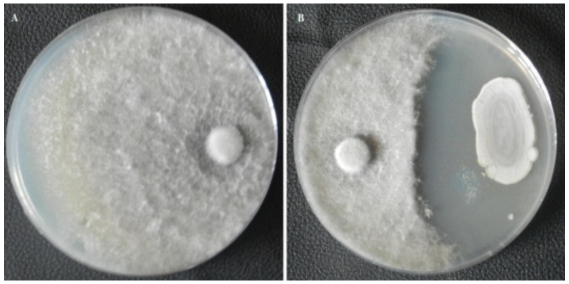


(Hoagland et al. in final prep, *Soil Biology and Biochemistry*)

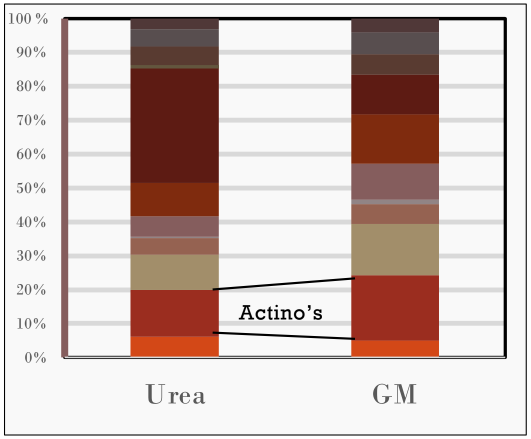
IMPACTS ON ACTIVE MICROBIAL COMMUNITY STRUCTURE

- Several microbial taxa often implicated in pathogen suppressive activity ***greater in GM***

  - Actinomycetales, Bacillales and Pseudomanadales



Antagonistic activity of *Actinomycetes* (right) against a fungal pathogen (left)



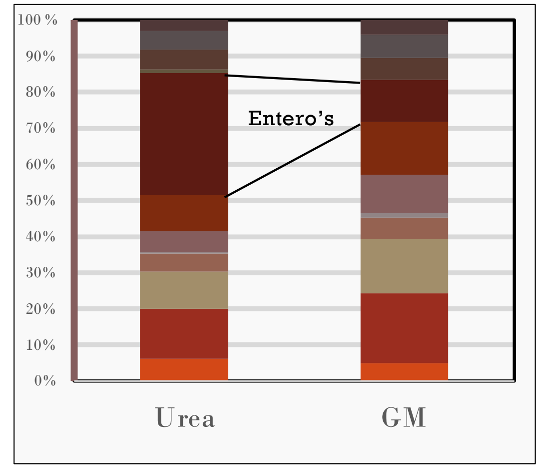
Relative abundance of dominant microbial in the rhizosphere by Order

Phylum	Class	Order	Family	Genus	Urea (OTU's)	Green manure (OTU's)
Actinobacteria	*Actinobacteria*	*Actinomycetales*	*Streptomycetaceae*	*Streptomyce*	15761	91297
Actinobacteria	*Actinobacteria*	*Actinomycetales*	*Micrococcaceae*	*Arthrobacter*	0	74621
Actinobacteria	*Actinobacteria*	*Actinomycetales*	*Proprionibacterineae*	*Nocardioide*	0	69552
Firmicutes	*Bacilli*	*Bacillales*	*Bacillaceae*	*Bacillus*	25217	86162
Proteobacteria	*Gammproteobacteria*	*Pseudomanadales*	*Pseudomonadaceae*	*Pseudomonas*	0	35078

(Hoagland et al. in final prep, *Soil Biology and Biochemistry*)

IMPACTS ON ACTIVE SOIL MICROBIAL COMMUNITY STRUCTURE

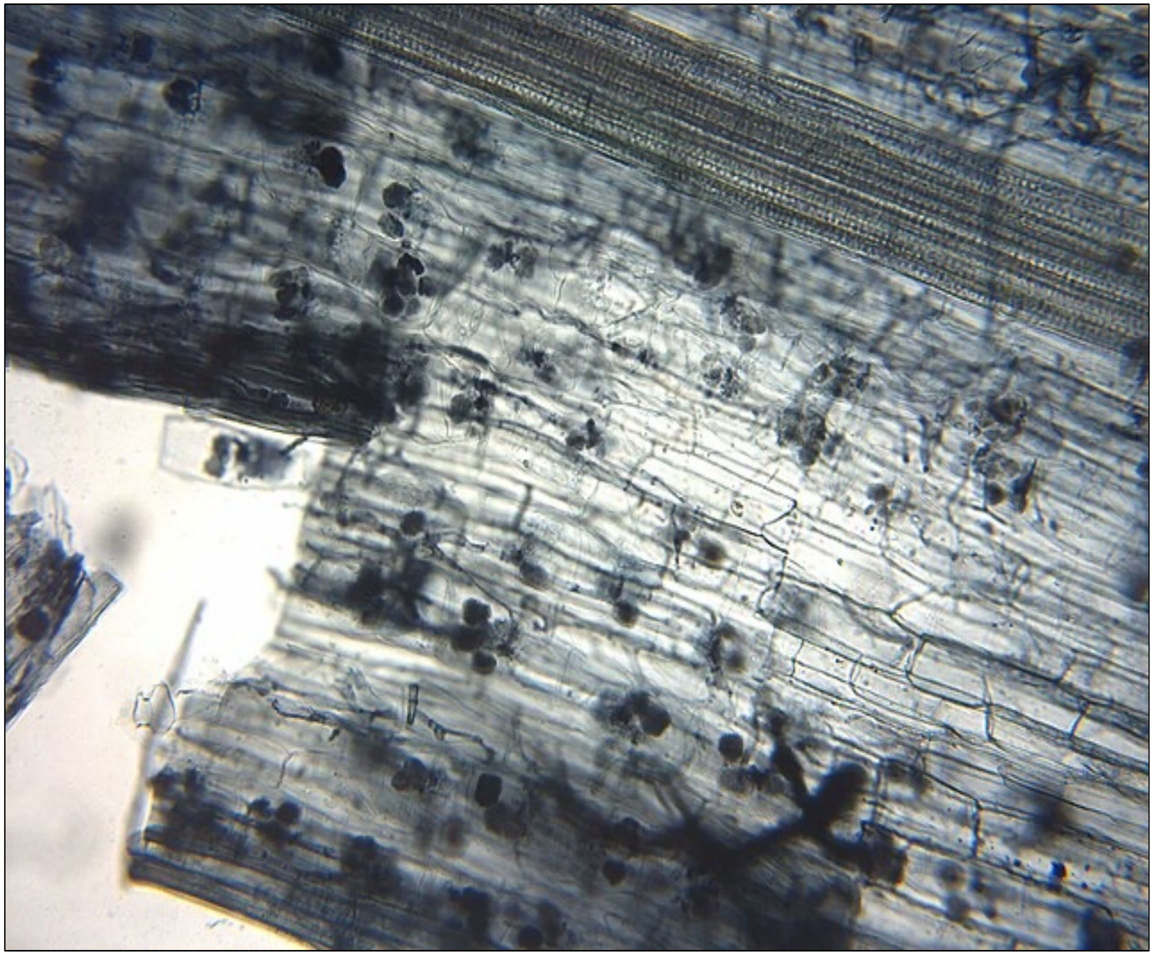
- Enterobacteriaceae, including several genera of potential enteric bacteria, ***much greater in the urea treatment***



Relative abundance of dominant microbial in the rhizosphere by Order

Phylum	Class	Order	Family	Genus	Urea (OTU's)	Green manure (OTU's)
Proteobacteria	*Gammproteobacteria*	*Enterobacteriales*	*Enterbacteriaceae*	*Escherichia/Shigella*	391504	182033
Proteobacteria	*Gammproteobacteria*	*Enterobacteriales*	*Enterbacteriaceae*	*Salmonella*	166046	80493
Proteobacteria	*Gammproteobacteria*	*Enterobacteriales*	*Enterbacteriaceae*	*Enterobacter*	112383	30891
Proteobacteria	*Gammproteobacteria*	*Enterobacteriales*	*Enterbacteriaceae*	*Cronobacter*	54589	0
Proteobacteria	*Gammproteobacteria*	*Enterobacteriales*	*Enterbacteriaceae*	*Yersinia*	46807	0

(Hoagland et al. in final prep, *Soil Biology and Biochemistry*)

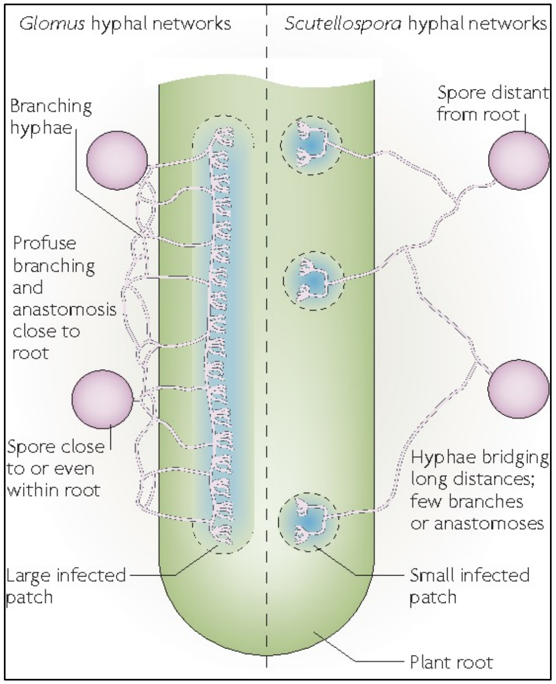


EXAMPLE #2

Cover crops, arbuscular mycorrhizal fungi (AMF), and implications for the health of crops and people

ARBUSCULAR MYCORRHIZAL FUNGI (AMF)

- Beneficial symbiosis between plant roots and fungi within the Glomeromycota
- Most well-studied beneficial root symbiosis
- Ancient relationships (400 mya); highly conserved across most (80%) plant species
- Numerous benefits for plants and fungi
- Actually quite diverse (*244-1600 species*) and benefits likely depend on species
- AMF species likely respond differently to soil/crop management practices, but impact on their benefits is less clear



Different hyphal growth and branching strategies in AMF (Parniske, 2008)

How can cover crops alter the composition and functional capacity of AMF?

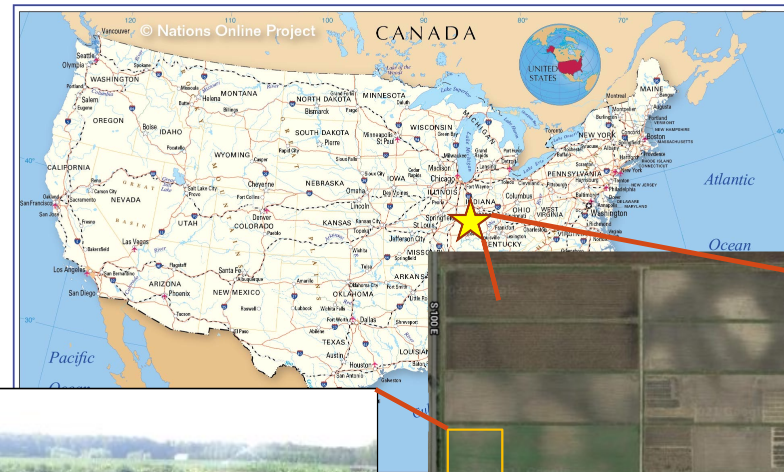
CROP SYSTEMS TRIAL AT MEIG'S FARM

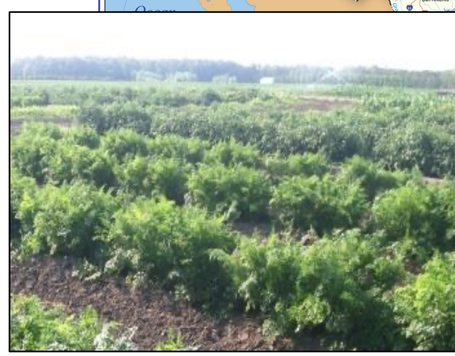
- Established on adjacent plots of land using organic and conventional management since 2000
- Four crop systems evaluated (2011-16)
- 4-year crop rotation in all systems

popcorn -> **edible soybean** -> tomato -> **carrot**

Conventional management system	Soil-building organic management system
• Inorganic fertilizers • Chemical pesticides	• Animal manure based fertilizer • Limited use of organic pesticides • Winter cover crop mixtures
Soil health declined	Soil health improved

Nutrient concentrations similar between two systems





- few differences in crop yield, but did observe *lower pest incidence* & *higher nutrient density* in crops from the organic soil-building system

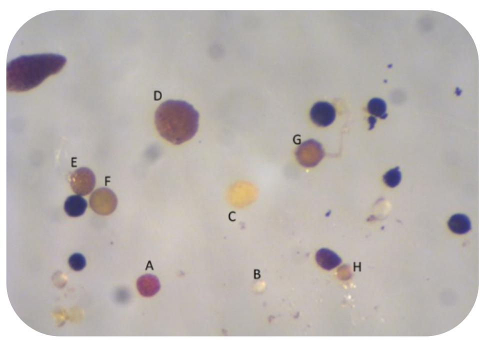
IMPLICATIONS FOR ROOT MICROBIOMES AND RESISTANCE TO BIOTIC AND ABIOTIC STRESS

- Carrots grown in the organic soil-building system hosted endophytic microbes with greater capacity to suppress carrot diseases (Abdelrazek et al., 2020 *PLOS One*; Abdelrazek et al., 2020 *Scientific Reports*)

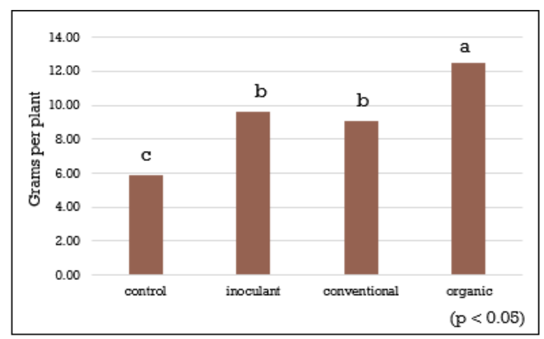
Dr. Sahar Abdelrazek

- Soybeans grown using **AMF** inoculum from the soil-building organic system helped soybean plants better resist drought and increased yield under stress (Zubieta, 2018)

Lisseth Zubieta



AMF spores types identified in soil from the organic soil-building system



Pod dry weight of soybean plants subject to water stress

HOW MIGHT DIFFERENCES IN AMF ALTER THE NUTRITIONAL QUALITY AND SAFETY OF CARROT CROPS?

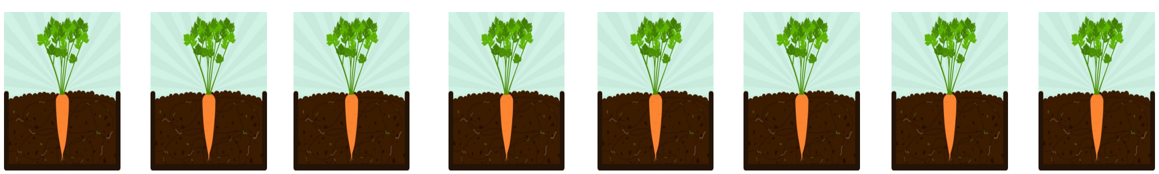

Hannah Komanapelli

- AMF are well-known for their capacity to help plant scavenge nutrients (*especially phosphorous, iron and zinc*), but the impact of AMF species on these dynamics is less clear
- AMF may also have potential to positively impact the uptake of toxic heavy metals and metalloids like cadmium, lead and arsenic
- Carrots can take up these toxic heavy metals putting consumers, especially babies at risk

  - *FDA's Closer to zero initiative*
- Can commercial inoculants displace native AMF species in soil and alter their benefits?

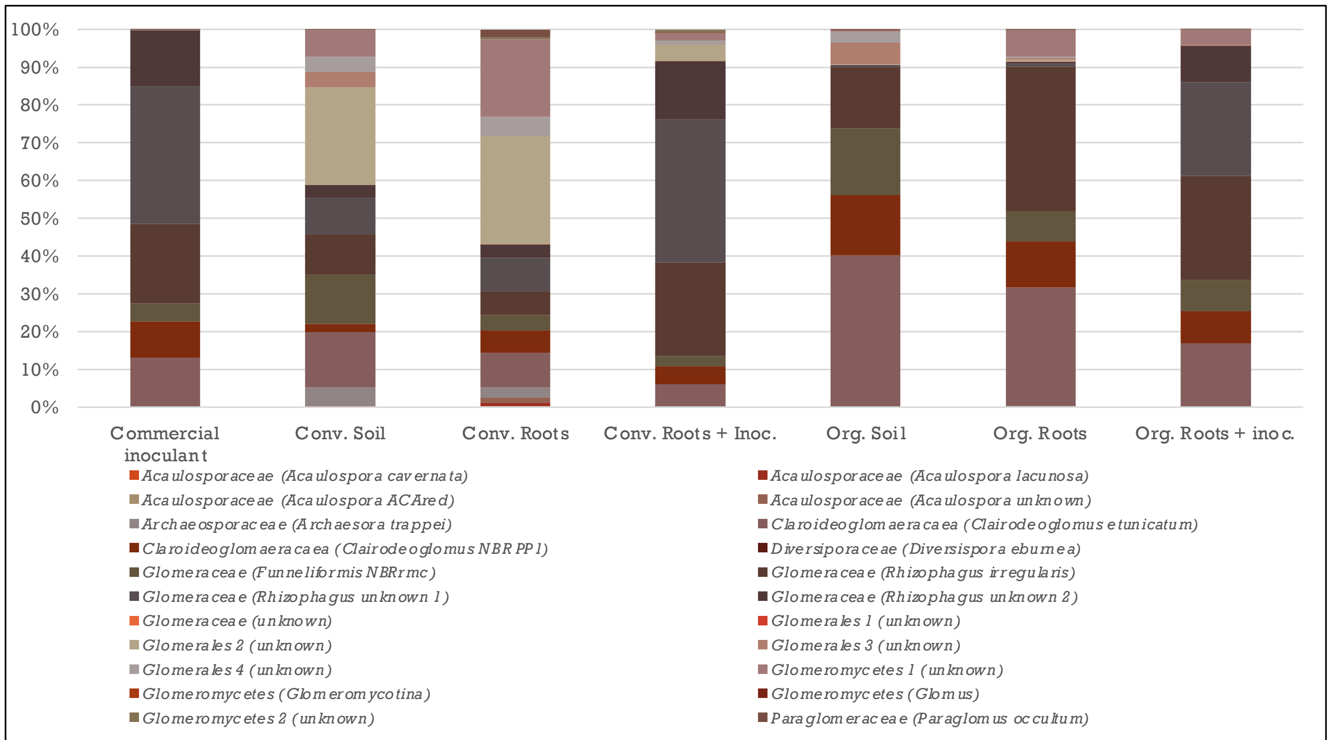
EXPERIMENTAL DESIGN

- Soil/root fragments collected from field trial after cover crop in spring prior to carrot planting
- Soils from field trials (with and without AMF) and a commercial inoculant (*Rhizophagus irregularis*) used as inoculum in sterile sand:soil mix
- Carrot (cv. Napoli) planted in each pot
- Quantified AMF communities in fine roots, as well as taproot yield and elemental concentrations



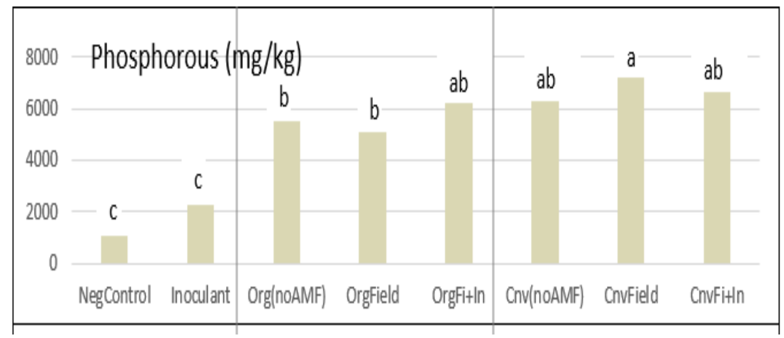
RESULTS: IMPACTS OF SOIL MANAGEMENT/HEALTH ON THE COMPOSITION OF AMF AND THEIR CAPACITY TO HELP CARROT PLANTS OBTAIN NUTRIENTS AND PREVENT CD UPTAKE

- Commercial AMF inoculants were not pure, but dominated by *Rhizophagus* species
- AMF in conventional systems were more diverse and dominated by *Glomerales* & *Rhizophagus*
- AMF in organic systems had greater concentrations of *Clariodeglomus*
- AMF in carrot roots reflected inoculum in soil and were impacted by the addition of the commercial inoculant

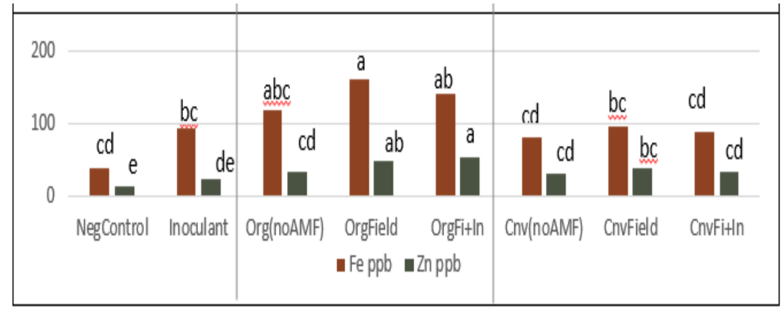


RESULTS: IMPACTS OF SOIL MANAGEMENT AND HEALTH ON THE COMPOSITION OF AMF AND THEIR CAPACITY TO HELP CARROT PLANTS OBTAIN NUTRIENTS AND PREVENT CD UPTAKE

- Phosphorous was higher with AMF communities from both field trials than with the commercial inoculant
- Iron and zinc were higher in taproots grown with AMF from organic field
- Small reduction in Cd with whole microbiomes from organic system (*AMF not acting alone – follow up studies underway*)
- Commercial inoculant did increase Cd uptake relative to control, but did not disrupt benefits of AMF from either field



Impact of AMF communities on phosphorous in taproots



Impact of AMF communities on iron and zinc in taproots

Komanapelli et al., in final prep for *Soil Biology and Biochemistry*

EXAMPLE #3

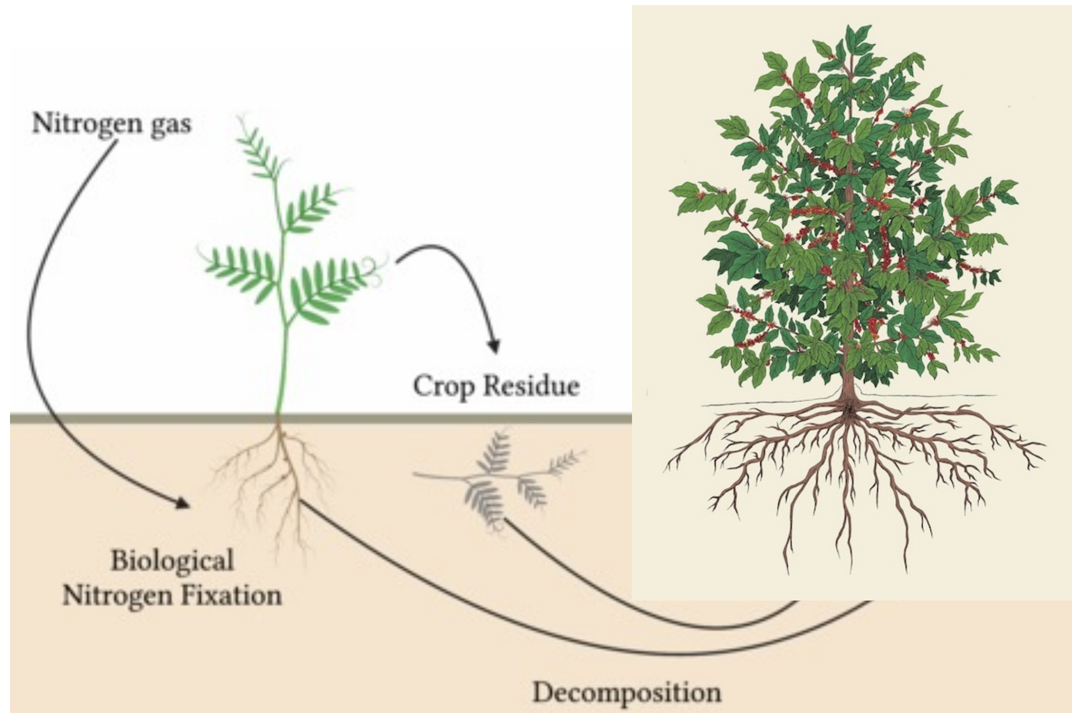
Legume intercropping on the composition and functional capacity of coffee root microbiomes

- Coffee: Main export crop in Colombia **- 3rd** largest producer in the world.
- Nitrogen (N): The most critical nutrient in coffee production – influences growth, yield and caffeine content.
- Increasing price of fertilizers/dependence on imports: ***Concern for coffee growers.***
- **Affordable and sustainable N sources are needed to decrease production costs and keep you caffeinated**

Taken from Pinterest Bing Images, 2024

LEGUME INTERCROPPING SYSTEMS HAVE POTENTIAL TO HELP MEET N NEEDS

- Legumes fix atmospheric N through microbial symbiosis with nitrogen-fixing bacteria.
- Legume intercropping systems also have potential to help mitigate soil erosion on steep hillsides.
- ***Integrating more diversity in an this critical agroecosystem through intercropping could also bring additional benefits for coffee plants by promoting beneficial root microbiomes.***



Modified from University of Minnesota Extension, 2022

(Salinas et al., in prep)

METHODS – INTERCROPPING FIELD EXPERIMENT

Locations:
3 experimental farms

1. Caldas:
2. Quindio
3. Cauca

X

Legume treatments:
Tephrosia sp. = Tephrosia
Cajanus cajan = Guandul
No legume = None

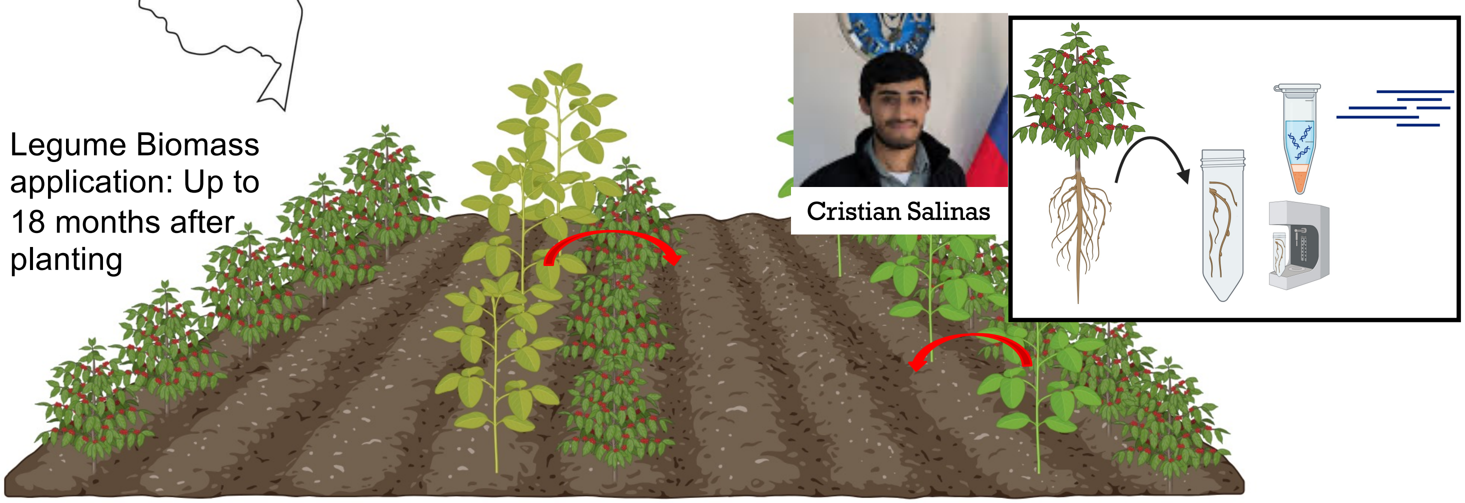
None: Caldas, Quindio, Cauca
Tephrosia: Caldas, Quindio, Cauca
Guandul: Caldas, Quindio

X

Nitrogen supply treatments:
0 = 0% of N required by plant
50 = 50% of N required by plant

None = 0 and 50 %
Tephrosia = 50 %
Guandul = 50 %

Legume Biomass application: Up to 18 months after planting

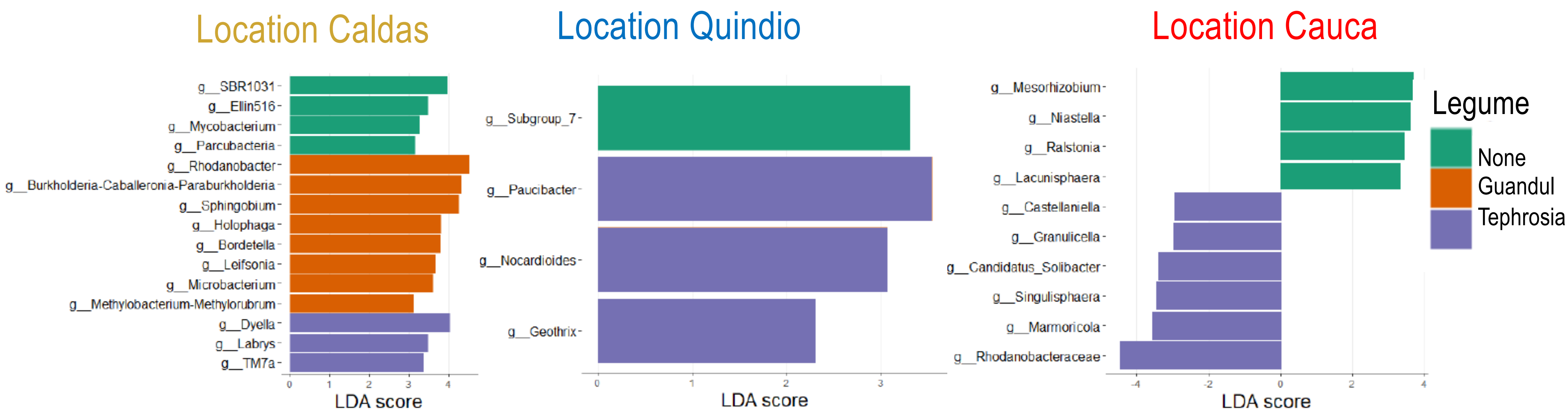


Created with BioRender.com

Cristian Salinas

Dr. Hernan Gonzalez Dr. Lucio Navarro
National Coffee Research Center - Cenicafe

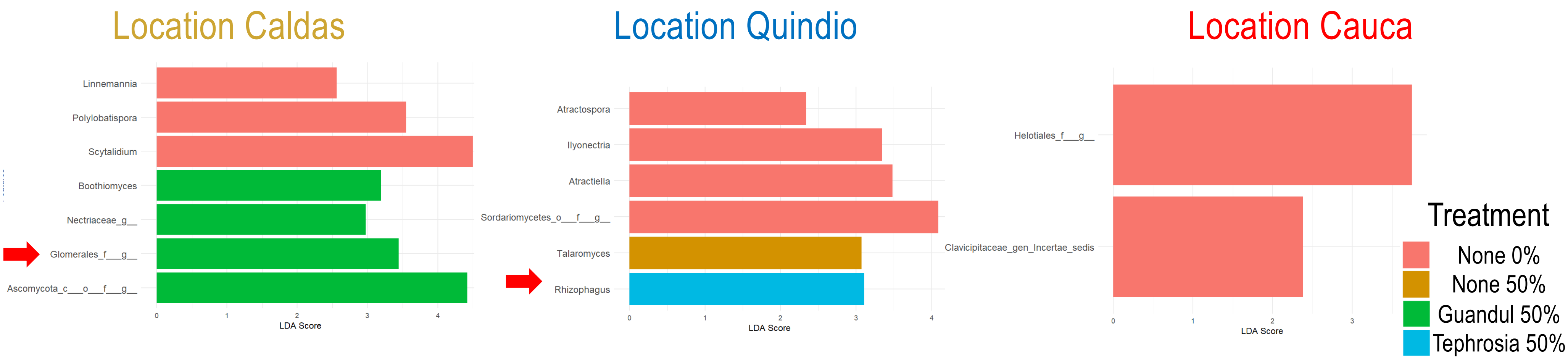
RESULTS: BACTERIA LEFSE ANALYSIS



Takeaways

- The most abundant bacterial genera in coffee roots varied across locations and legume treatment.
- *Sphingobium sp.* and *Leifsonia sp.* were enriched in coffee grown with the Guandul intercrop treatment.
  - *Leifsonia* could help coffee plants solubilize P and improve coffee growth
  - *Sphingobium* could produce plant growth hormones (gibberellins and ACC deaminze) that aid in root growth and nutrient uptake
- *Dyella*, *Labrys* and *Nocardiodes* were enriched in coffee grown with the Tephrosia intercrop treatment
  - These organisms could support root growth, enhance N cycling, and suppress disease-causing pathogens.

RESULTS: FUNGI LEFSE ANALYSIS



Takeaways

- The most abundant fungal genera in coffee roots also varied across locations and legume treatment.
- Arbuscular mycorrhizal fungi (AMF) species in coffee were differentially impacted by the legume intercrops
  - *Rhizophagus* had a higher relative abundance in coffee roots grown with the Tephrosia intercrop treatment
  - *Glomerales* sp. had a higher relative abundance in coffee roots grown with the Guandul intercrop treatment
  - Both sp. have potential to provide multiple benefits to coffee plants

EXAMPLE #4 (*LAST ONE*)

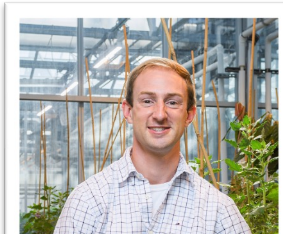
Leaf mold compost, soil health, microbial inoculants and pathogen dynamics

COMPOST

- Quickest way to build organic matter and improve soil tilth on degraded soils (*improve 'soil health'*)
- Can provide supplemental nutrients to meet crop fertility needs
- ***Some composts have also been demonstrated to make soils more disease suppressive***
- Compost quality (*and benefits*) depends on feedstocks and processing conditions

Decomposed organic materials (e.g. plant & animal wastes)

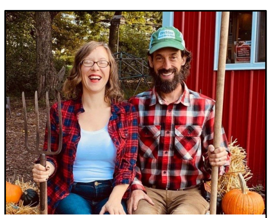
FIELD TRIAL WITH 'LEAF MOLD' COMPOST



Kyle Richardville

http://efc.web.unc.edu/2014/03/28/financing-urban-agriculture-growing-field-possibilities/

- Many benefits to farming in the city, but soils are often highly degraded, and in some cases contaminated
- Urban growers often apply ample amounts of composts to improve soils and meet plant fertility needs (but *can also add too much compost – soils often way over enriched in P*)
- ***Are there urban waste products that can improve soils and crops without enriching soil? Can they also better support microbial inoculants and support a more circular economy in cities?***
- Midwest cities have lots of deciduous tree leaves (*resource for fungi*)



Dan & Julie Perkins
Good Earth Farm

Received: 28 August 2021 | Accepted: 29 November 2021
DOI: 10.1002/uar2.20022

ORIGINAL RESEARCH ARTICLES

Urban Agriculture & Regional Food Systems

Leaf mold compost reduces waste, improves soil and microbial properties, and increases tomato productivity

Kyle Richardville[1] | Dan Egel[2] | Andrew Flachs[3] | Amit Jaiswal[1] | Dan Perkins[4] | Aaron Thompson[1] | Lori Hoagland[1]

'**Leaf mold**' – passive composting process (*thought to encourage fungi*); not contaminated with metals

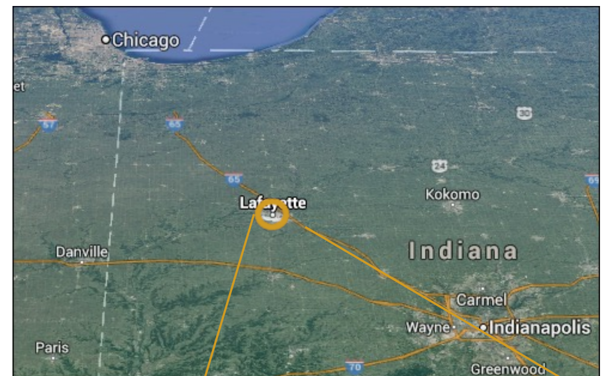
EXPERIMENTAL DESIGN

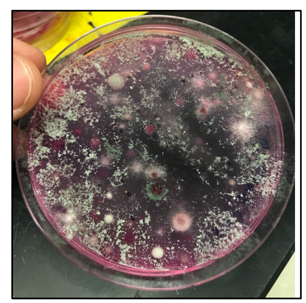
- Field trial at Purdue's urban Student Farm on Cherry road (2019-2020)

Research questions:

1) **Can leaf mold compost improve soil and plant health and suppress disease in tomato?**
2) **Can leaf mold compost increase survival of a commercially available biocontrol inoculant (*Trichoderma harzianum T22) in the field?***

   - RCBD w/ 2 tomato genotypes and 4 replicates;T22 applied at seeding in trays and again to soil in field; repeated in new location each year to verify results
   - Tracked range of 'soil health' parameters (*e.g. active organic matter, microbial activity, etc.*) and crop responses (*disease, yield, etc.*)
   - Tracked T22 inoculant using plate counts/qPCR

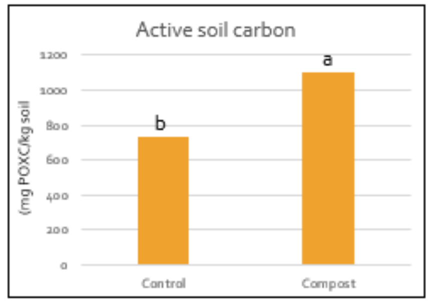




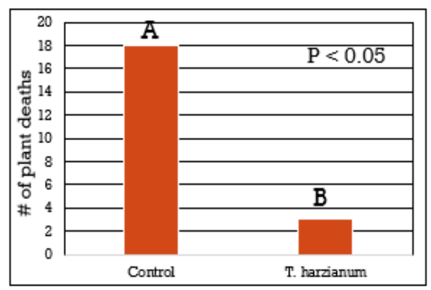
RESULTS – DRAMATIC INCREASES IN SOIL HEALTH AND CROP PRODUCTIVITY

- **60% increase in marketable fruit yield!!!**

- Large increases in key 'soil health' properties due to compost -> (*e.g. active soil carbon, microbial activity, & abundance of potentially 'beneficial' soil microbes*)
- Reduction in tomato plant deaths after transplant when inoculated with T22
- Small reduction in foliar disease due to compost amendment
- Greater survival of T22 with compost & greater reduction in disease due to compost + T22



Impact of leaf mold compost on active soil carbon



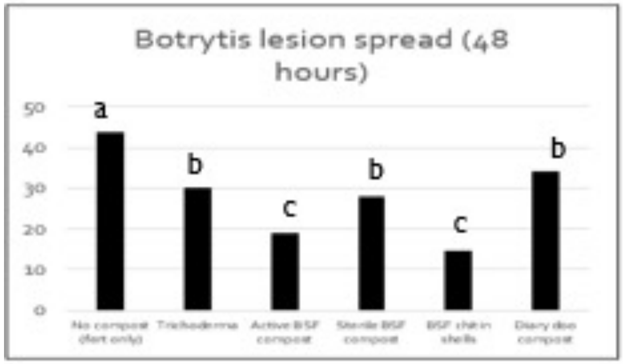
Effect of *T. harzianum* on W55 transplant stress in 2020

GREENHOUSE TRIALS WITH OTHER TYPES OF COMPOST

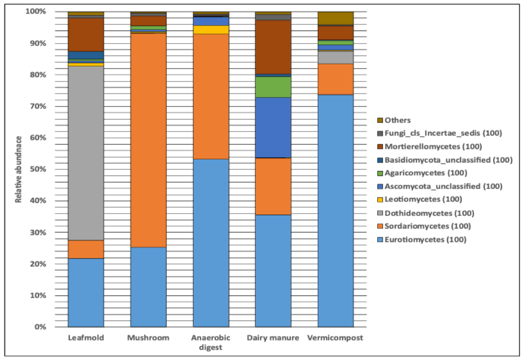
- Some, but not all composts reduced the spread of pathogen legions on tomato leaves
- Black soldier fly compost (Dr. Laura Ingwell) and derivatives of the process more suppressive than other composts
- Suppressive activity of composts in both trials correlated with presence of unique microbiomes
- **Additional trials underway including options for 'seeding' beneficial microbiomes in transplants w/ Dr. Liz Maynard**

Dr. Laura Ingwell, Purdue

Dr. Liz Maynard Purdue



Botrytis cinerea lesion size on tomato leaves 48 hours after inoculation. Columns with different letters significantly different at $p<0.01$. (*unpubl.)*



Relative abundance of fungal microbiomes in composts by class (unpublished)

SUMMARY AND CONCLUSIONS

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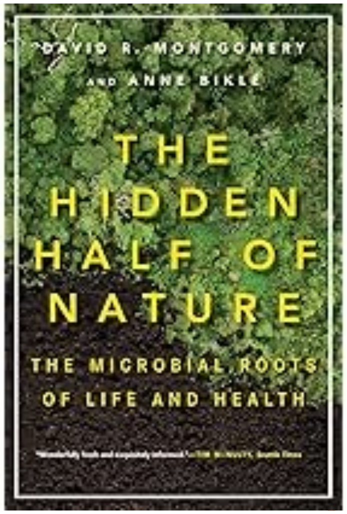
- Root microbiomes can influence the health and productivity of crop plants and this could also have important implications for human health
- It is possible to support beneficial root microbiomes in horticultural and field crops by integrating cover crops (*in both time and space*) and amending soils with high quality compost, *but be careful not to add too much compost*
- **The health of soils, plants and people are connected**



QUESTIONS?