SOIL HEALTH AND PEST MANAGEMENT

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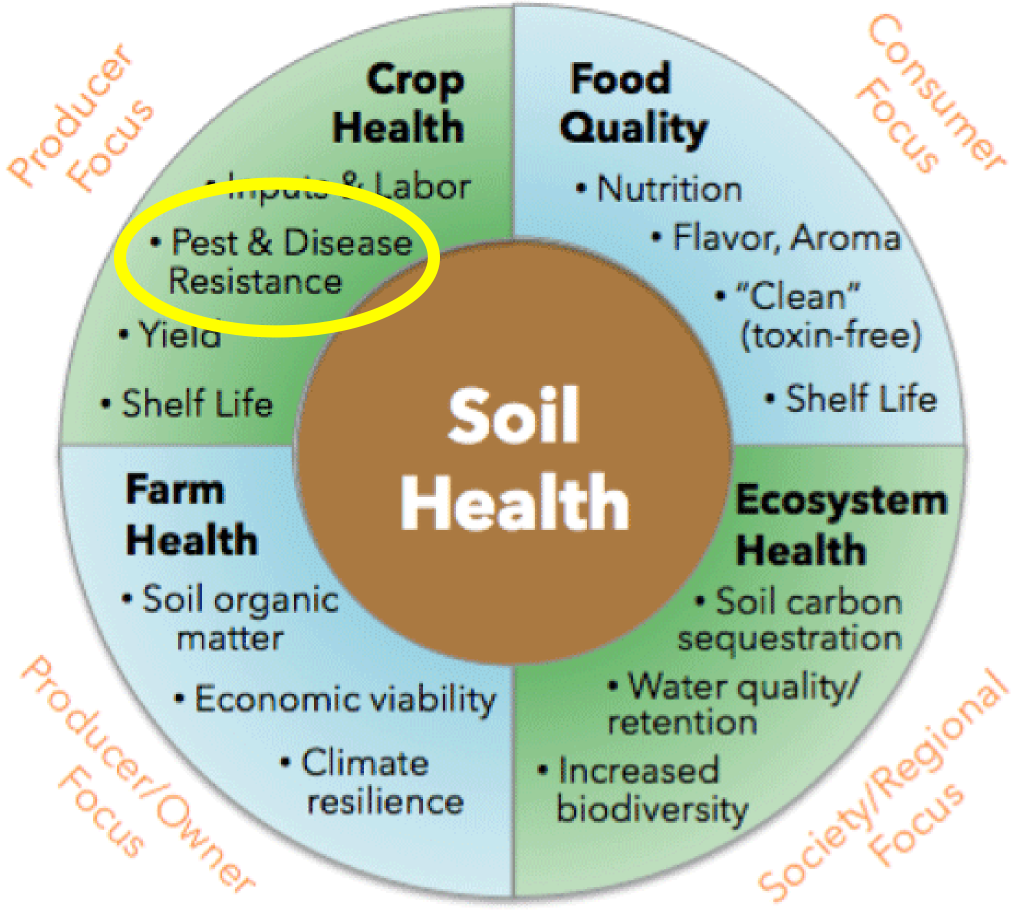
OUTLINE

- What causes pest outbreaks and how can they be avoided?
- Biological mechanisms mediating suppressive soil
- Management strategies for inducing suppressive soil
- Results of field trials demonstrating relationships between soil health and biotic and abiotic stress



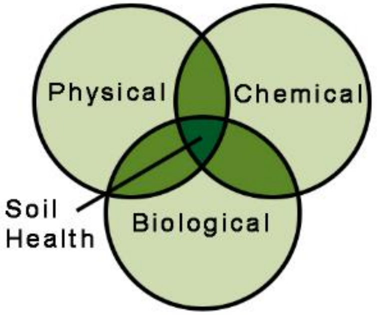
CHALLENGE

- Plant pests dramatically reduce crop yield and quality
- Need for alternative control practices
  - Non-target effects of pesticides
  - Host and fungicide resistance
- Food-borne pathogens

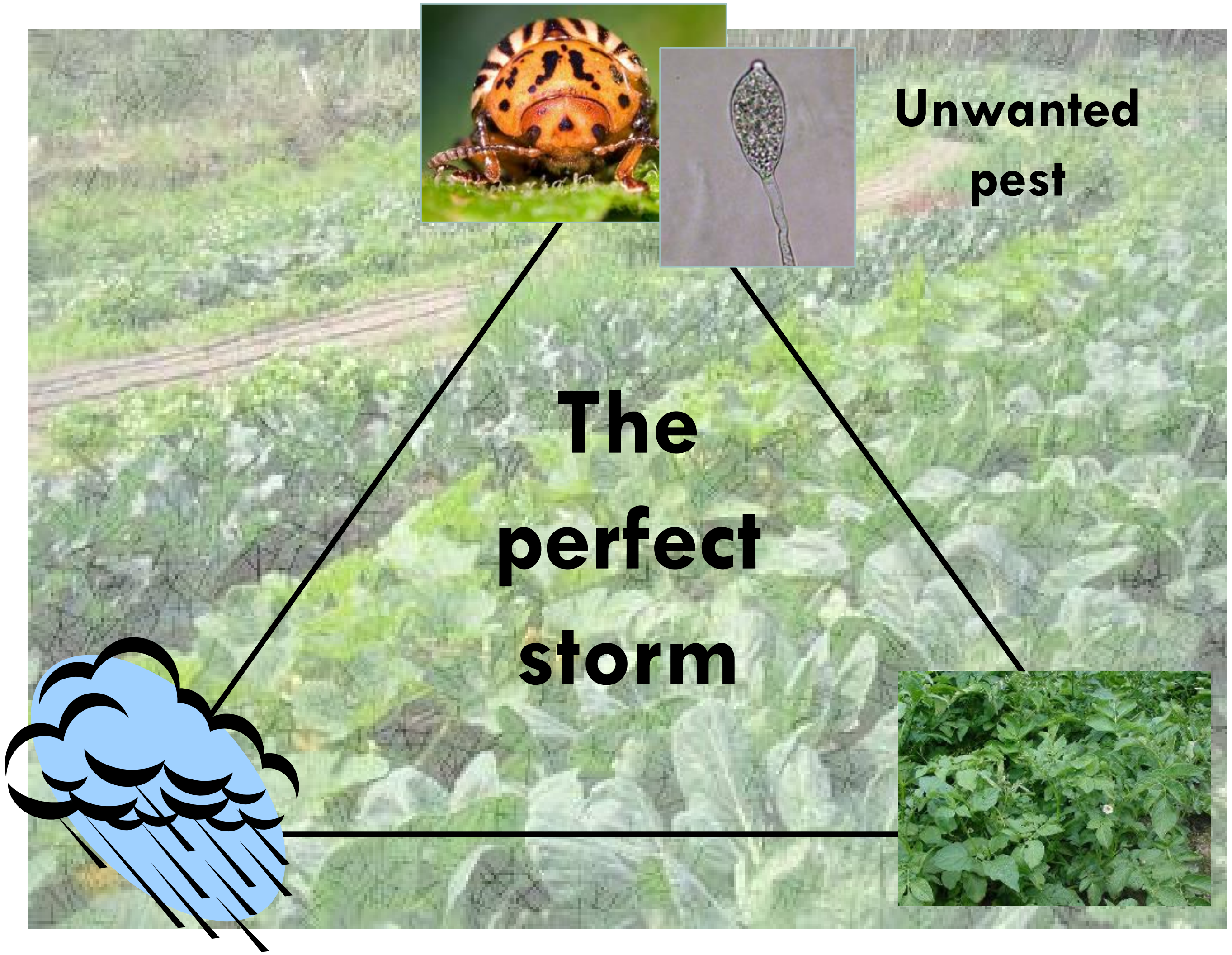
http://dhhs.ne.gov/publichealth/EPI/Pages/Foodborne.aspx

DISEASE TRIANGLE

- Physical barriers
- Increasing airflow



Favorable environment



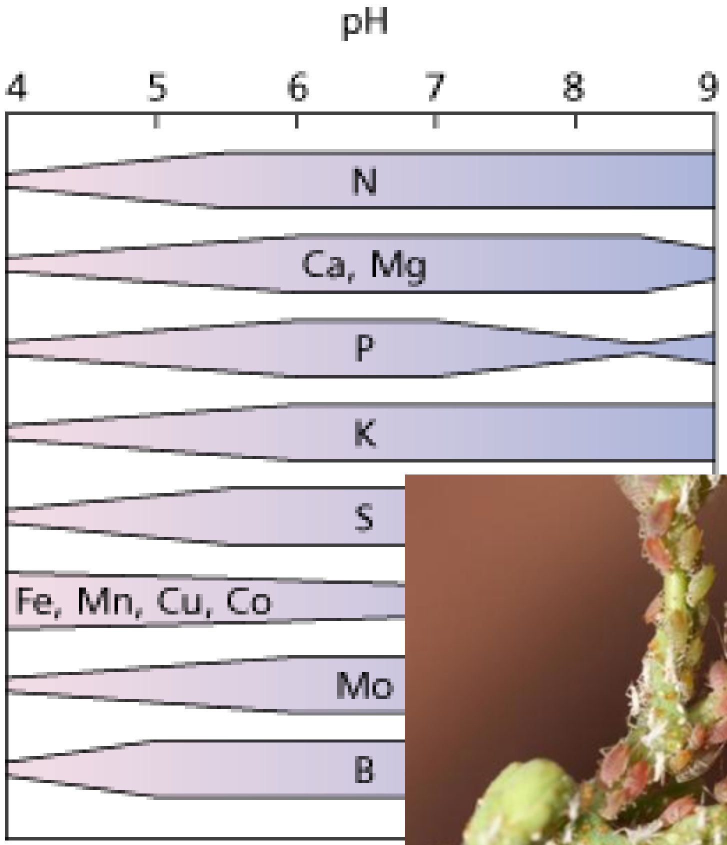
- Crop rotation
- Clean equipment
- Acting quickly to remove infected material

- Resistant varieties
- Varietal mixtures

Susceptible host

SOIL CHEMICAL PROPERTIES

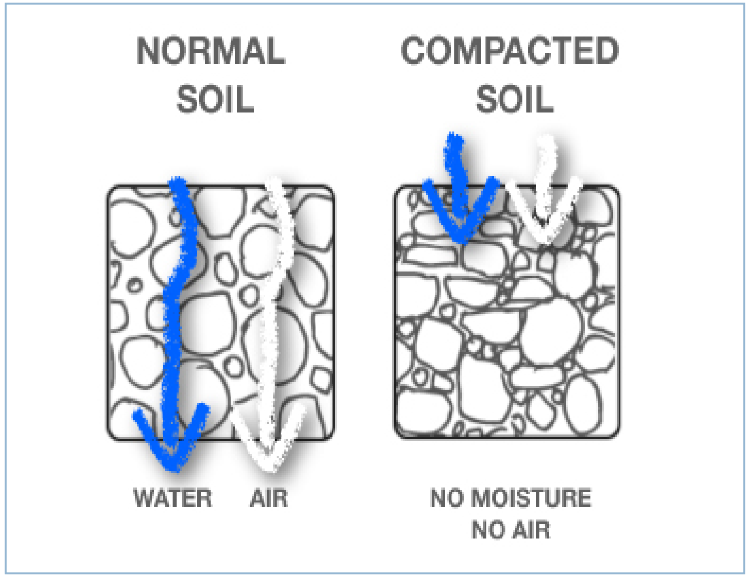
- pH: acidity/alkalinity of soil
  - nutrient availability
  - pathogen severity
- Nutrient availability
  - over and under fertilization
- Salinity: salt content of the soil
  - soil tilth and plant health



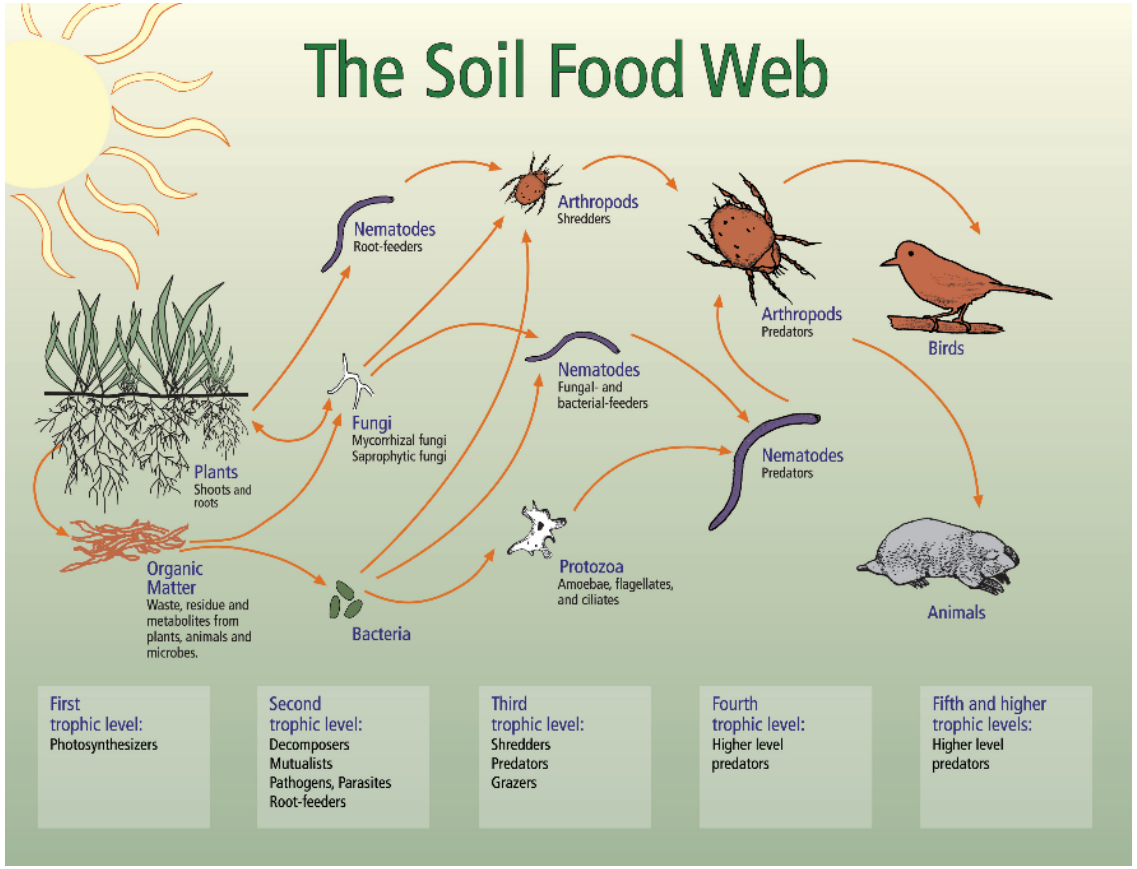
Whitney Cranshaw, Colorado State University, Bugwood.org

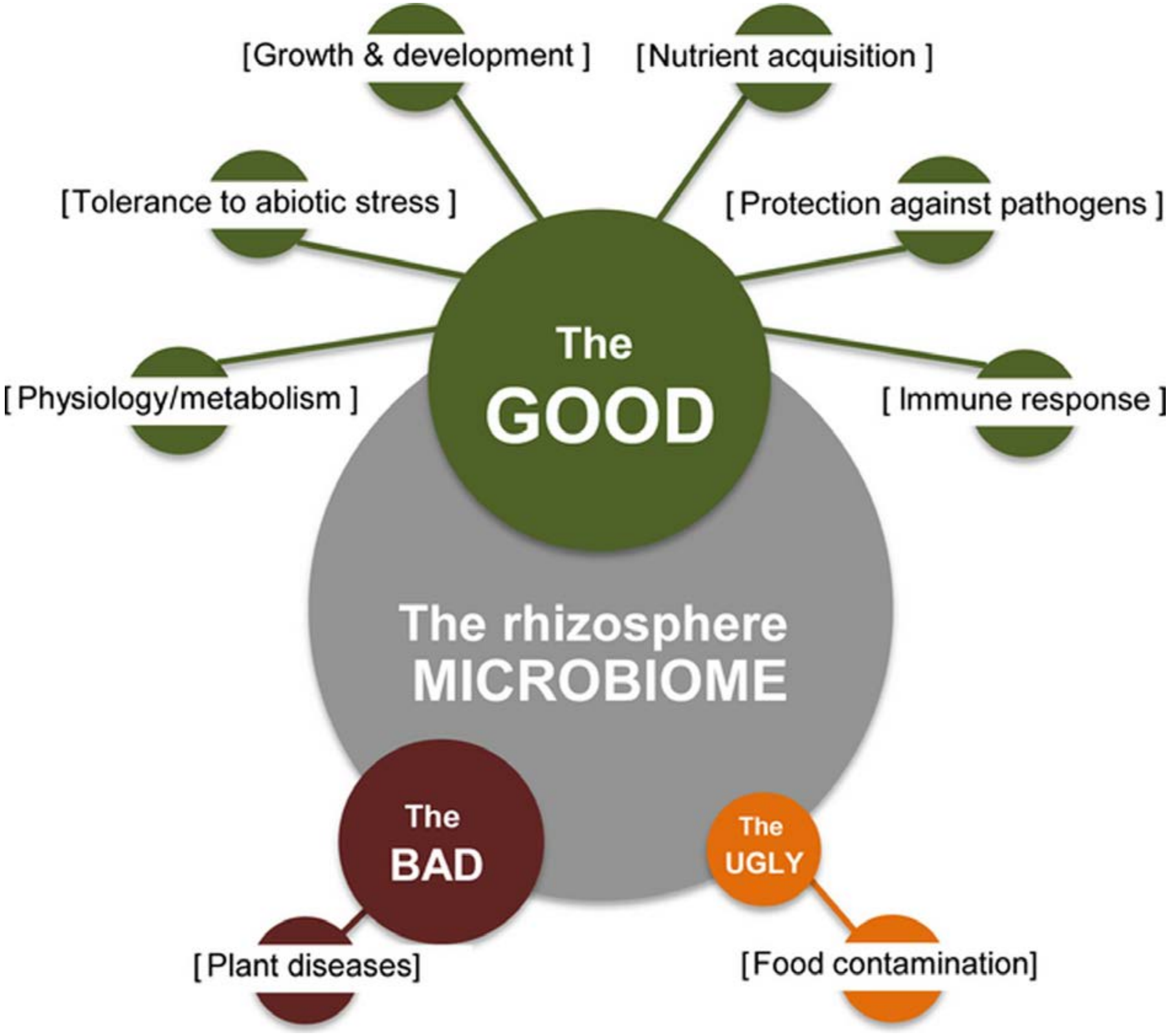
SOIL PHYSICAL PROPERTIES

- Compaction affects water infiltration and drainage
- Seed germination, root growth, oomycete habitat



SOIL BIOLOGICAL PROPERTIES





The Good, The Bad, and The Ugly

(Mendes et al., 2013)

DISEASE SUPPRESSIVE SOIL

What is it and how does it work?

DISEASE SUPPRESSIVE SOIL

- ***Suppressive soil***: Pathogen fails to persist or cause infection despite presence of susceptible host and favorable environment
- 1st documented in late 1880's
- Since been observed in multiple pathosystems worldwide

http://www.wur.nl/en/show/Role-of-Beneficial-Bacteria-in-Disease-Suppressive-soils.htm

Biological nature of suppression now documented

DETERMINING BIOLOGICAL RELATIONSHIPS

- Suppression is observed when soil is transferred to the greenhouse in controlled studies
- Suppression is eliminated upon pasteurization or radiation
- Suppression can be transferred by inoculating conducive soil with suppressive soil

http://www.wur.nl/en/show/Disease-suppressiveness-of-soil-reduces-pesticides-use.htm

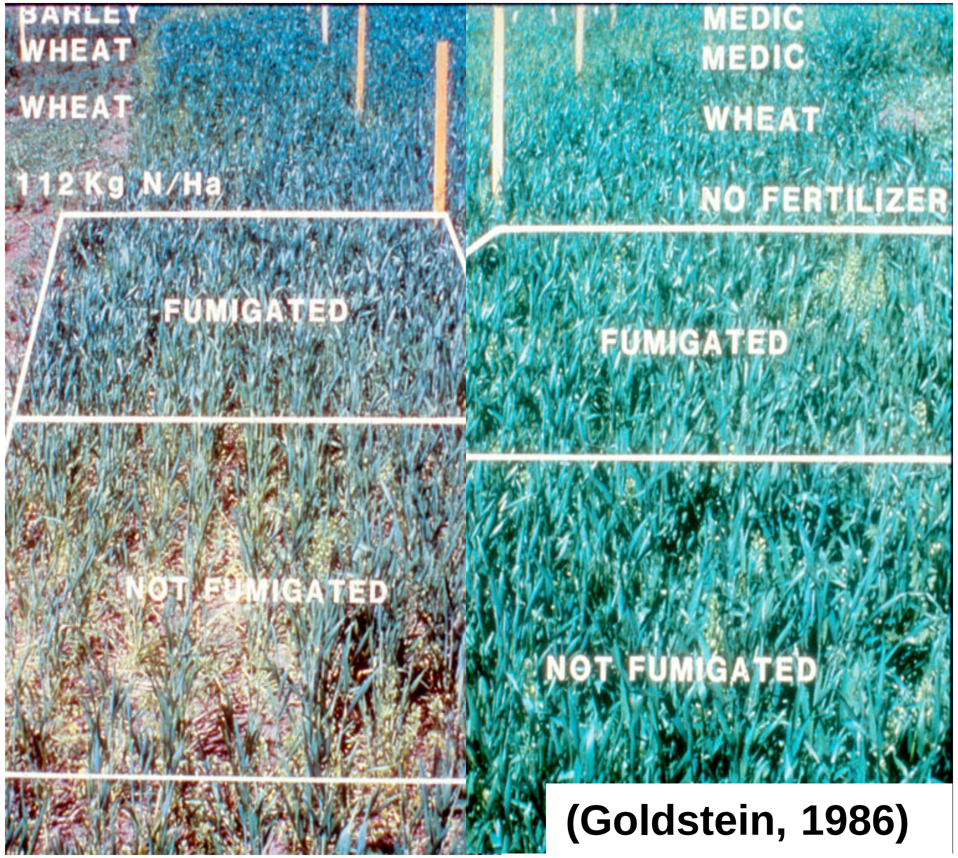
SPECIFIC SUPPRESSION

- Develop over time in monoculture systems
- Specific to a given pathogen

Gaeumannomyces graminis* var. *tritici **_Psuedomonas flourescences_**

GENERAL SUPPRESSION

- Function of overall soil health
- Highly correlated with soil biological activity
- *Multiple mechanisms of action*
- Can be induced by management
- ***Operates along a continuum; is not absolute***



(Goldstein, 1986)

BIOLOGICAL MECHANISMS MEDIATING SUPPRESSIVE SOIL

How can soil organisms suppress pests?

COMPETITION

- Occupy niches on the root surface

  - chemotaxis (*move towards the root*)

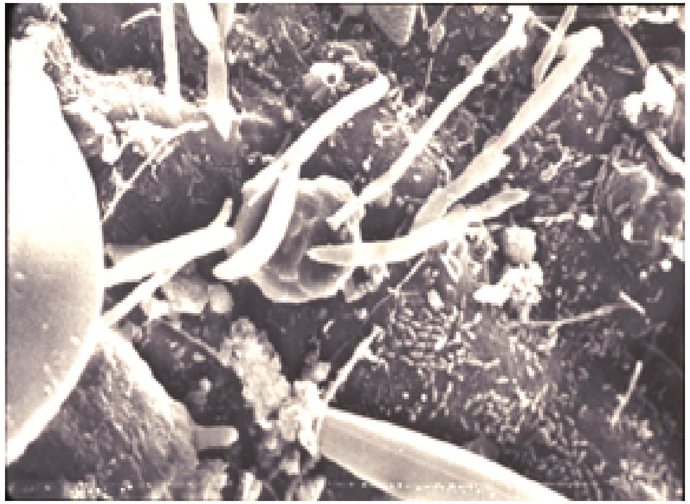
  - efficient nutrient utilization

- Nutrient acquisition

  - produce siderophores (*high affinity Fe chelators*)

    - reduce Fe availability for pathogens

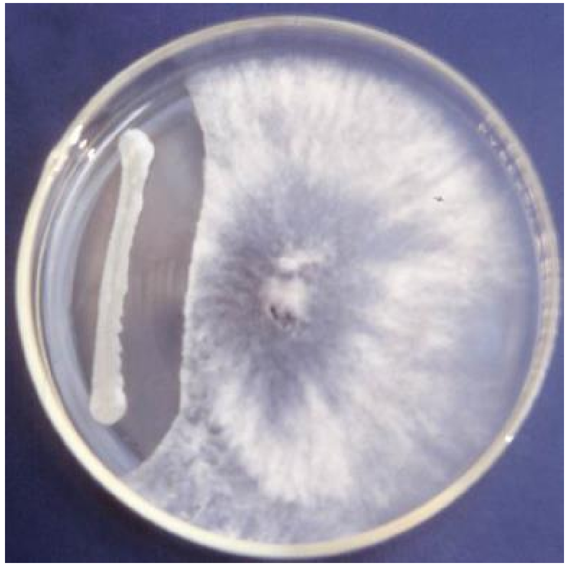
    - ie. pyoverdin (pseudomonas)



http://www.biomed.cas.cz/mbu/enztech/en_projekt.php?name=en_bakterialni_siderofory

ANTIBIOSIS

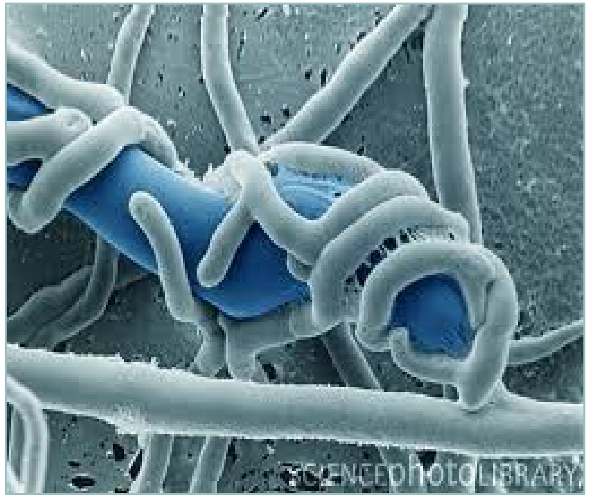
- Production of antimicrobial metabolites that are detrimental to another organism
  - Lytic enzymes degrade fungal cell walls and virulence factors
  - Insecticidal activity
- Trigger defensive capacity in plants
- Produced by 1/3rd of all rhizosphere bacteria
- *Coproduction of multiple compounds can result in synergistic effects*



http://www.pv.fagro.edu.uy/fitopato/cursos/fitopato/practicas/10/Antibiosis1.JPG

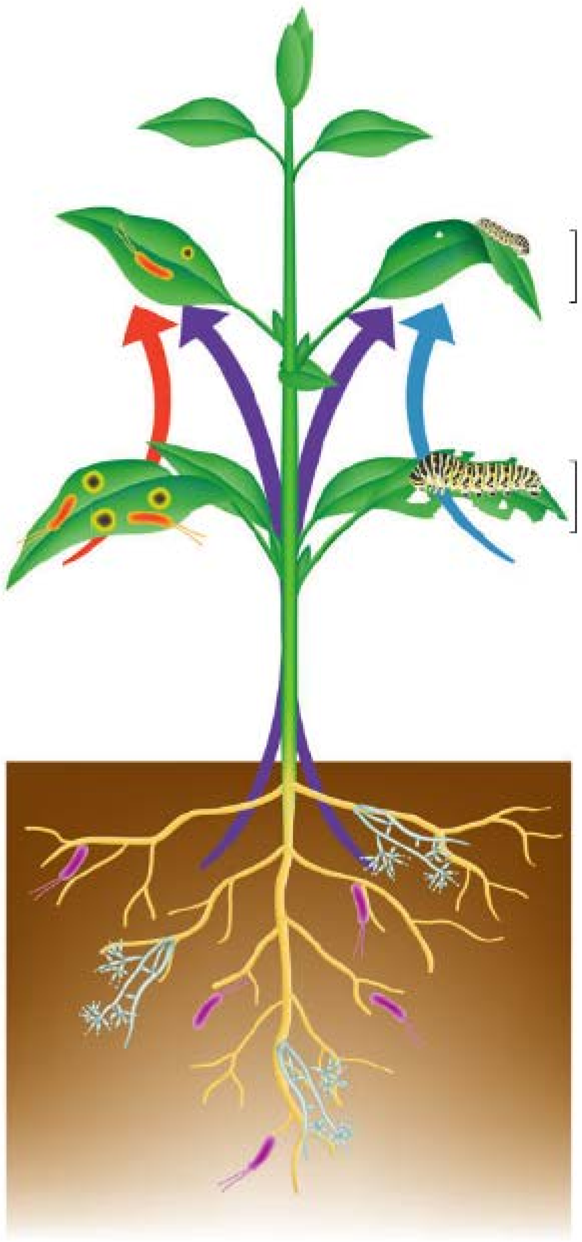
PREDATION & PARASITISM

- Entomopathogenic nematodes
- *Trichoderma* and *Gliogladium*
  - Molecules released from pathogens triggers chemotaxis
  - Produce exoenzymes that degrade fungal cell walls (chitinases and celluases)
  - Hyphae coil around the pathogen and further degrade cell walls
- Endosymbionts can modify biology of fungi – silencing virulence & altering development morphology



INDUCED SYSTEMIC RESISTANCE

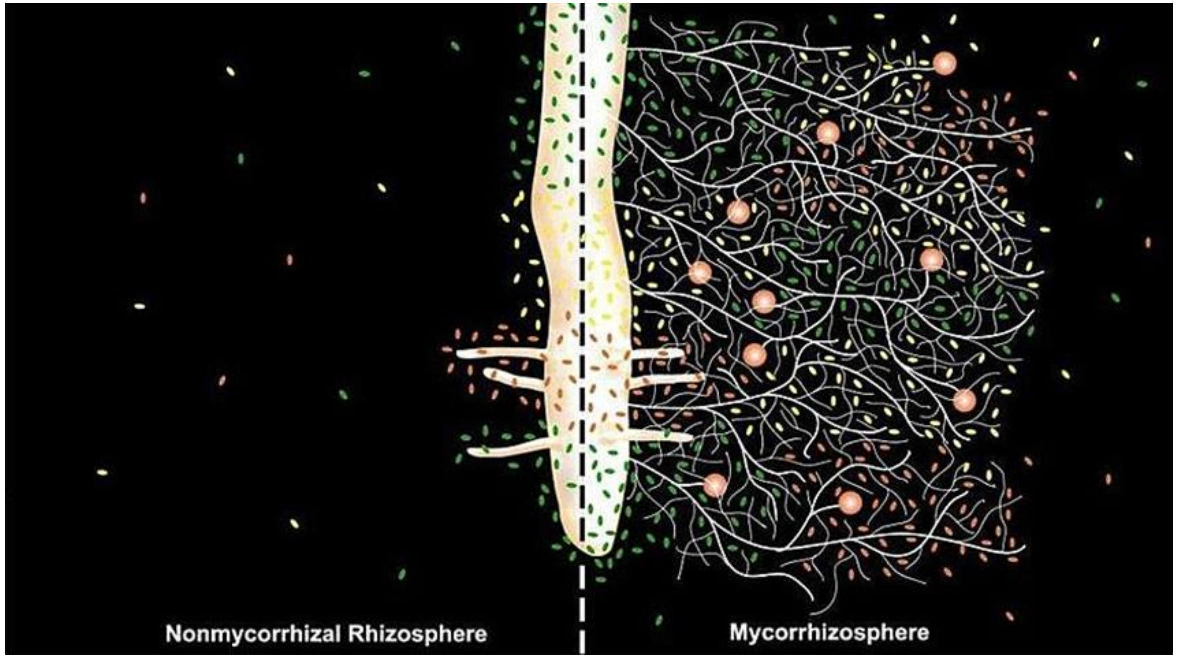
- Broad spectrum 'priming' reaction in the plant conferring enhanced defense against a broad range of ***pathogens*** and ***insect herbivores***
- Mediated by chemical signals within the plant
- Triggered by wide range of bacteria, fungi and endophytes and their products (*lipopolysaccharides, siderophores, volatiles, etc.*)
- *Key area of on-going research*



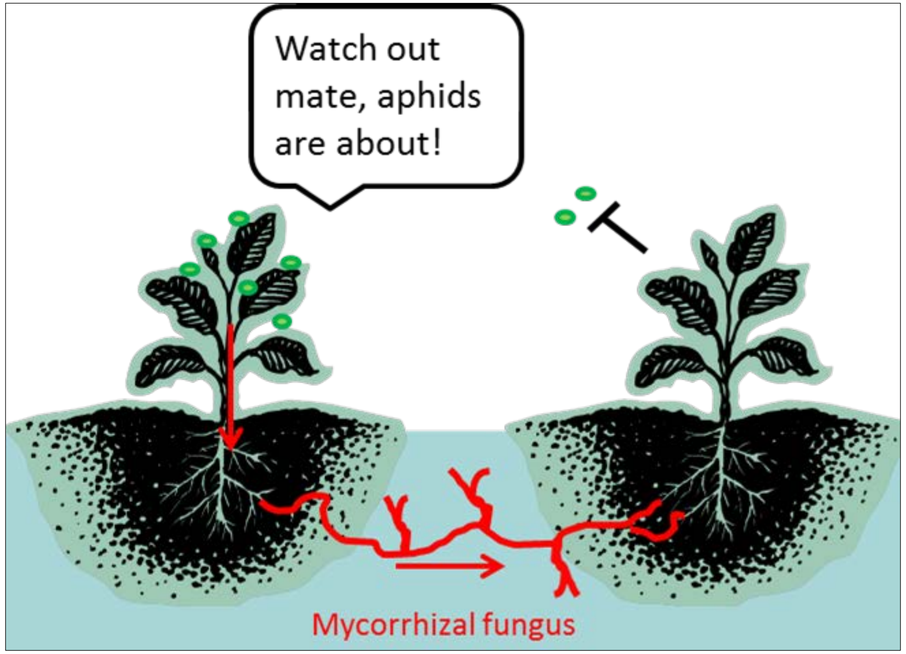
https://www.researchgate.net/publication/262929979_Induced_Systemic_Resistance_by_Beneficial_Microbes

RESOURCE ACQUISITION AND INTERPLANT COMMUNICATION

- Example: Mycorrhizal fungi



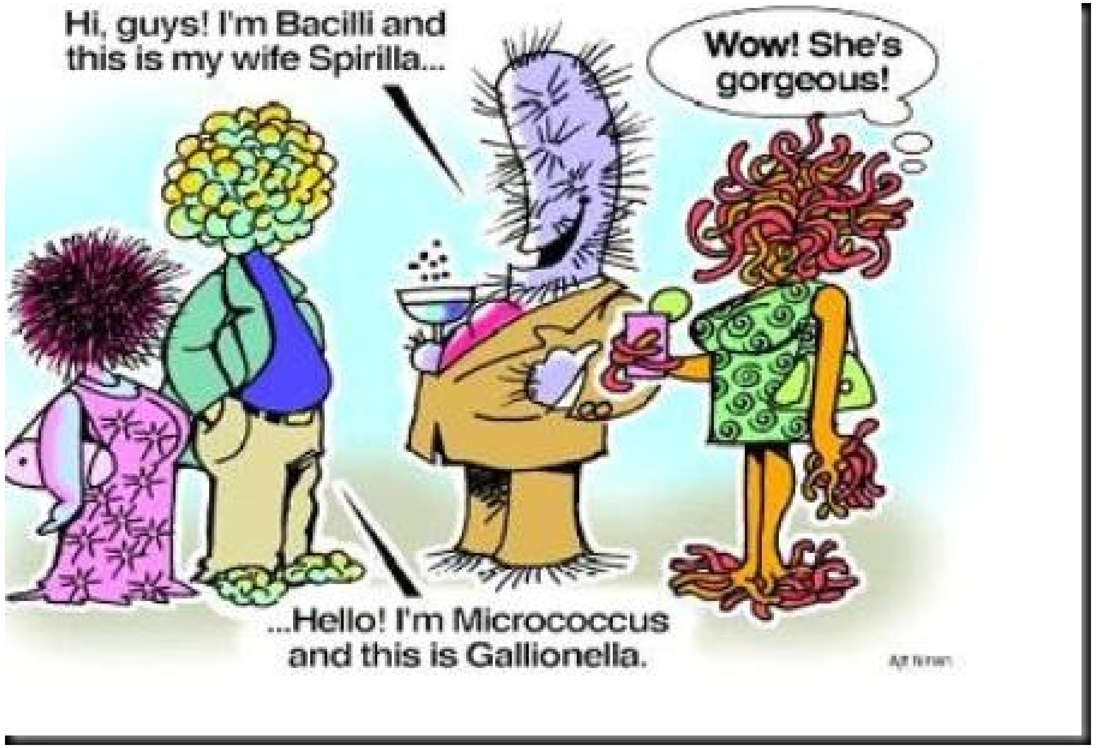
http://www.mycorrhiza.eu/e/home-e



https://plantscientist.wordpress.com/2013/06/24/watch-out-mate-aphids-are-about-plant-to-plant-communication-via-mycorrhizal-fungi/

HOW CAN SOIL BECOME MORE PEST SUPPRESSIVE?

Which approaches could be most useful?



https://www.google.com/search?q=beneficial+microbes&biw=1680&bih=989&source=lnms&tbm=isch&sa=X&sqi=2&ved=0ahUKEwjjs5vs6YrPAhWL44MKHd7XAB8Q_AUICCgD#imgrc=7IpApK0SnISeaM%3A

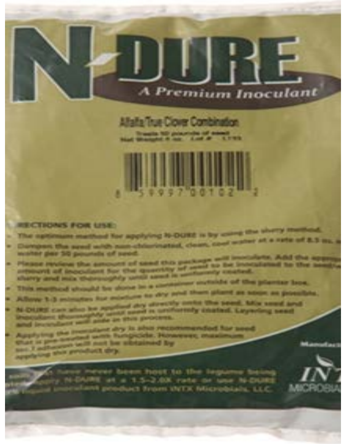
INTRODUCE BENEFICIAL MICROBES

EXAMPLES OF SUCCESSFUL MICROBIAL INOCULANTS

- Symbioses
  - Rhizobia and legumes
- *Trichoderma harzianum* (T22)
  - Improve germination
  - Suppress gray mold (*Botrytis cinerea*) in greenhouse trials
  - Reduce transplant stress in field

  (Hoagland et al., 2011)
- Controlled environment agriculture






CHALLENGES WITH MICROBIAL INOCULANTS IN THE FIELD

Intense competition with the natives

One ACRE

3" deep

~ 4.5 x 10^{16} Bacteria

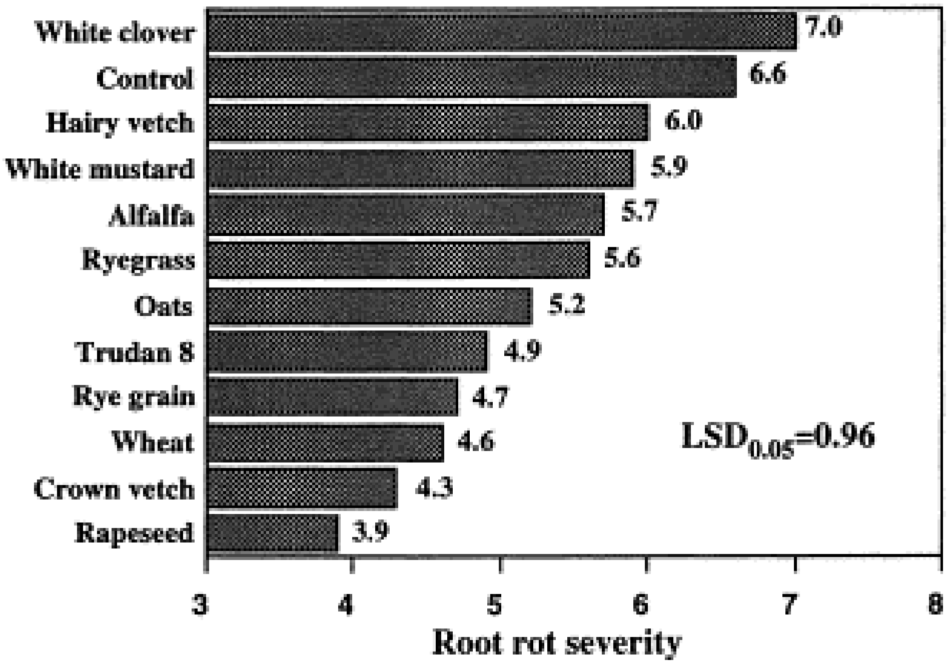
ADD: 1 gal of 1,000,000 cells per mL/acre
Alters the total population 0.00003%

PROVIDE A FOOD SOURCE

Build it and they will come

COVER CROPS

- Many examples of suppressive effects
- Potential mechanisms
  - Break disease cycles (*non-host crop*)
  - Allelopathy
  - Improve soil chemical & physical properties
  - ***Increase beneficial microbes***
- ***Challenge: suppressive activity could depend on the pest, plant species, and plant genotype***

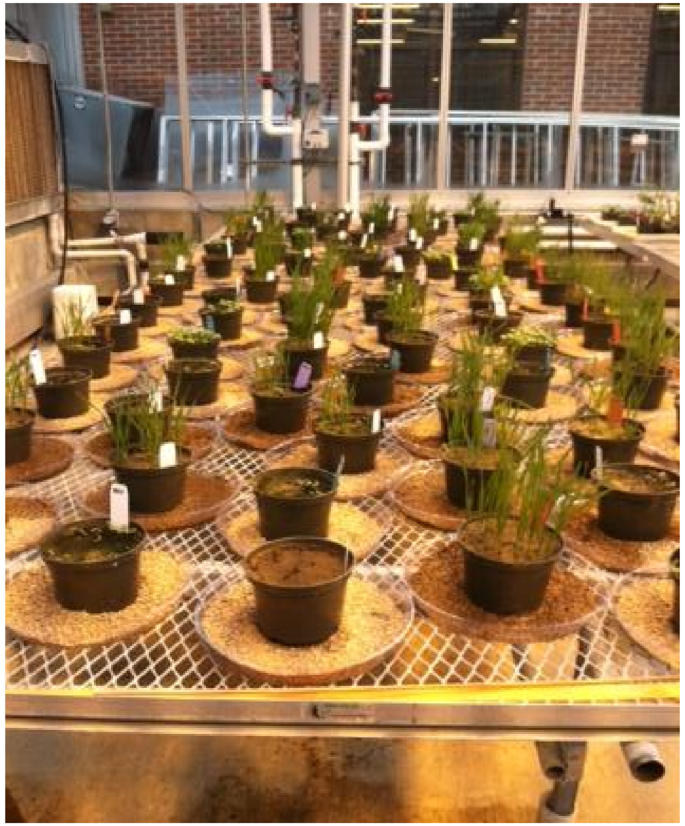


The effects of various incorporated cover crops on root rot severity of snap bean (*P. vulgaris* L.) in a greenhouse test. Roots were rated on a scale of 1 (no root rot observed) to 9 (>80% of the roots infected). Numbers after the bar graph represent the actual values. Statistical differences compared by Fishers least significant difference test ($LSD_{0.05}$). (Abawi et al., 2001)

BIOCONTROL OF PHYTOPHTHORA BLIGHT WITH COVER CROPS

- Phytophthora blight (*Phytophthora capsici)*
  - Spreads rapidly in infested field
  - Fungicide resistance
  - Broad host range and produces resilient spores
- Greenhouse trial
  - 2 naturally infested field soils
  - Caliente mustard mix
  - Cereal Rye
  - One of three wheat varieties (Penewawa, IN1131, and 1N4021)
  - Susceptible pepper cv. 'California Wonder'

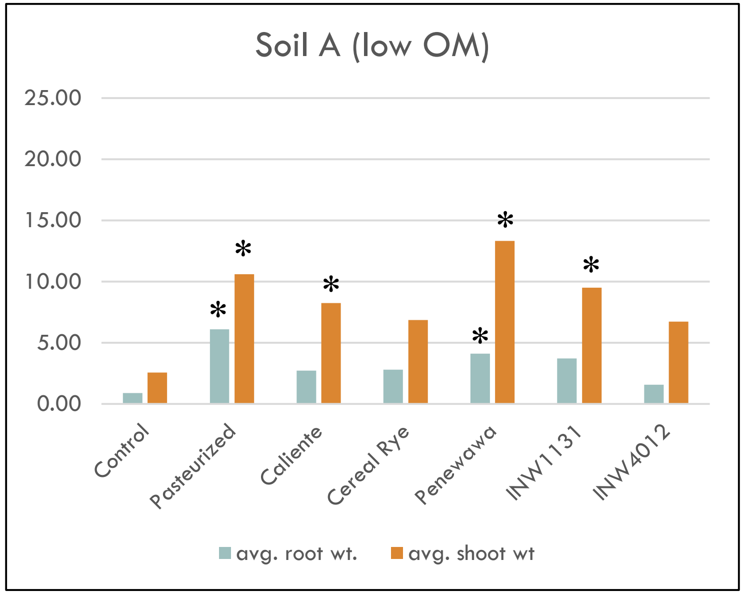
Soil	Soil tupe	% OM	pH
A	Sandy loam	1.3	7.1
B	Silt loam	4.5	6.9

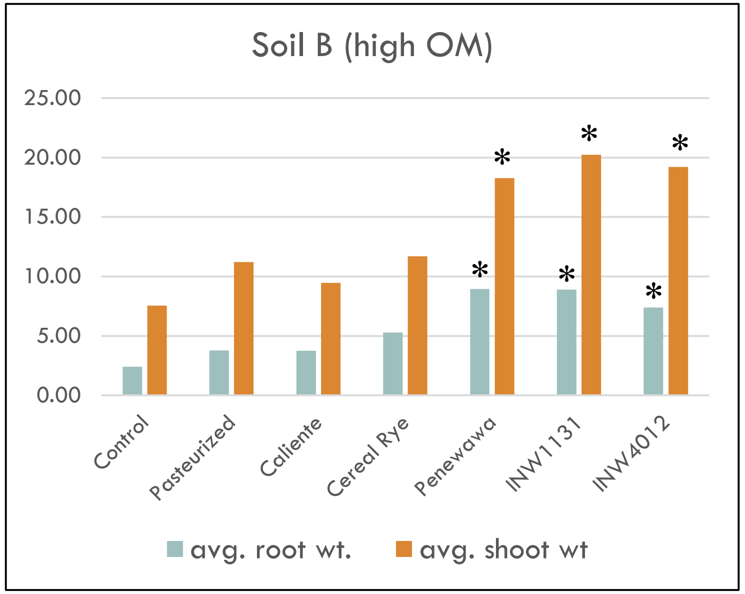


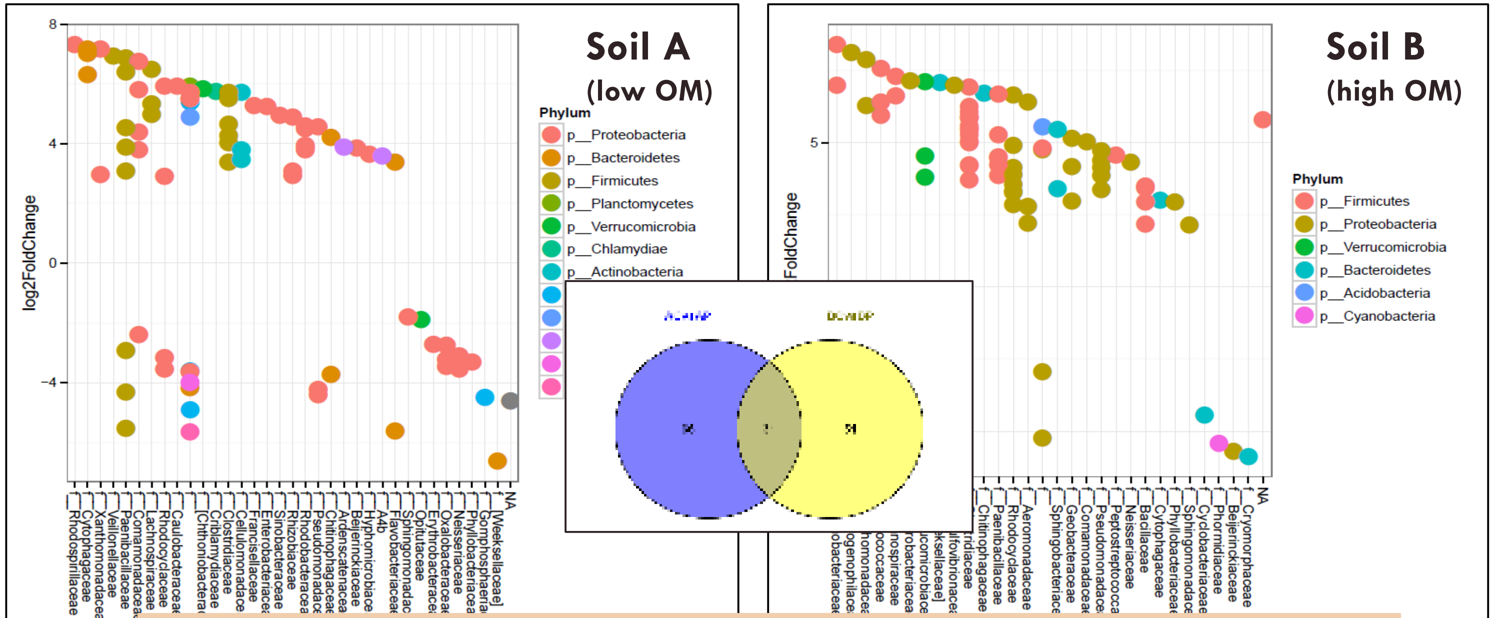
RESULTS

- Only wheat cv. Penewawa suppressed *P. capsici* and increased pepper root and shoot growth in both soils
- Suppressive activity by Penewawa was correlated with distinct changes in pepper rhizosphere community structure
- Overlap in change in taxa among both soils

(Hoagland et al., in prep)

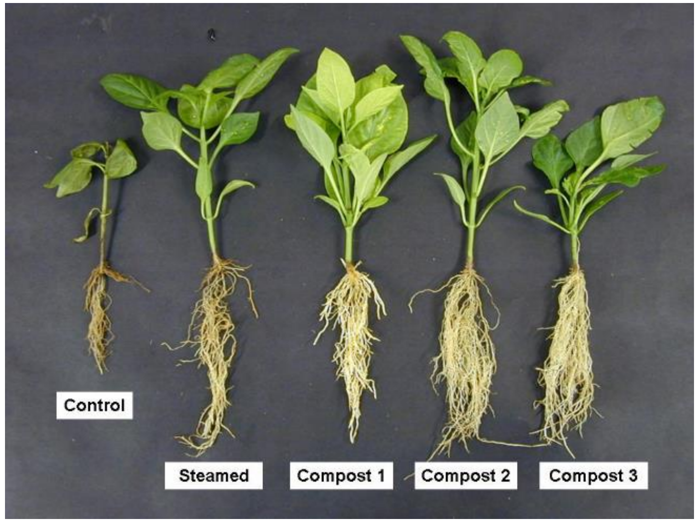






Change in pepper rhizosphere community structure following Penewewa

ORGANIC SOIL AMENDMENTS



http://www.compostforsoils.com.au/index.php?id=38

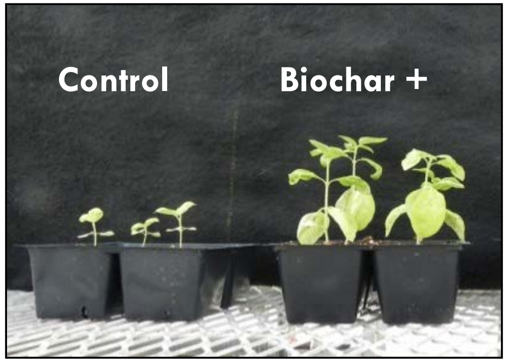
- Many examples of suppressive effects, particularly with compost in container-based systems

- Potential mechanisms
  - Improve soil chemical & physical properties
  - ***Increase beneficial microbes***

- ***Challenge: not all amendments are suppressive, variability in field trials, and high rates could be needed***

BIOCONTROL OF PHYTOPHTHORA BLIGHT WITH SOIL AMENDMENTS

- Biochar
  - Improve nutrient and water retention and increase crop yields
  - Suppressive activity in multiple pathosystems

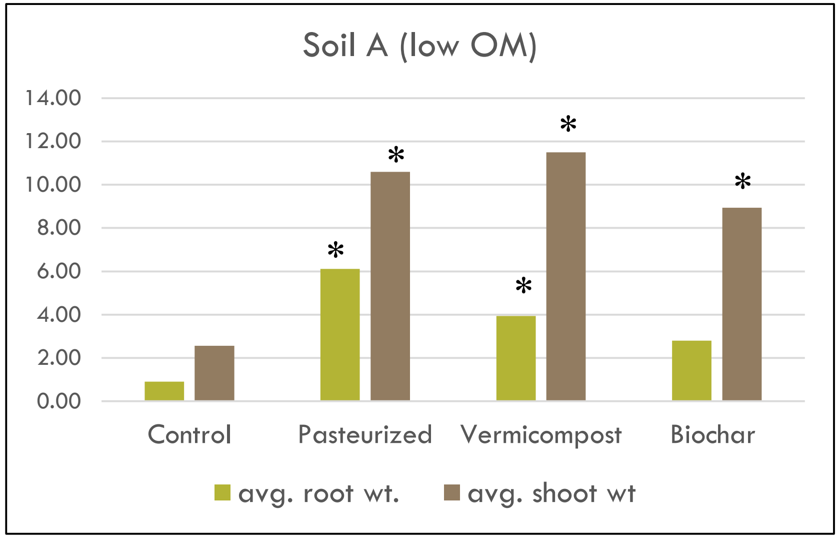


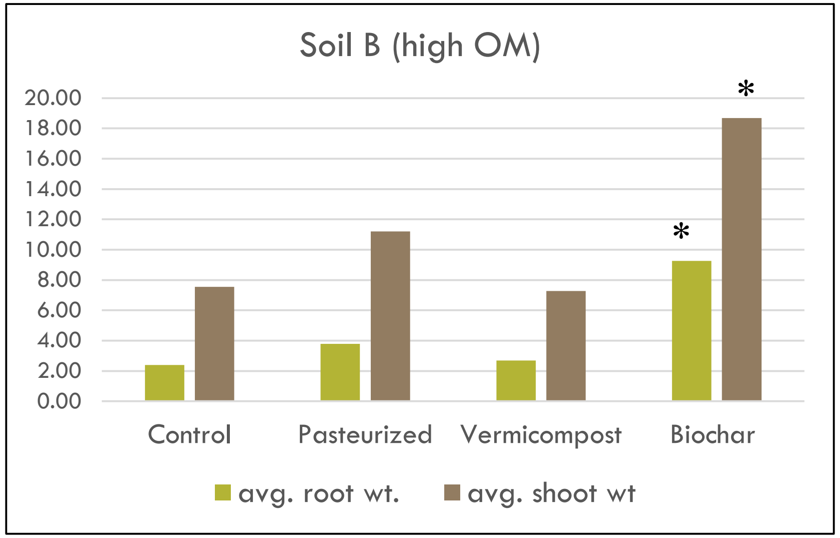
- Vermicompost
  - Readily available nutrient source
  - Suppressive activity

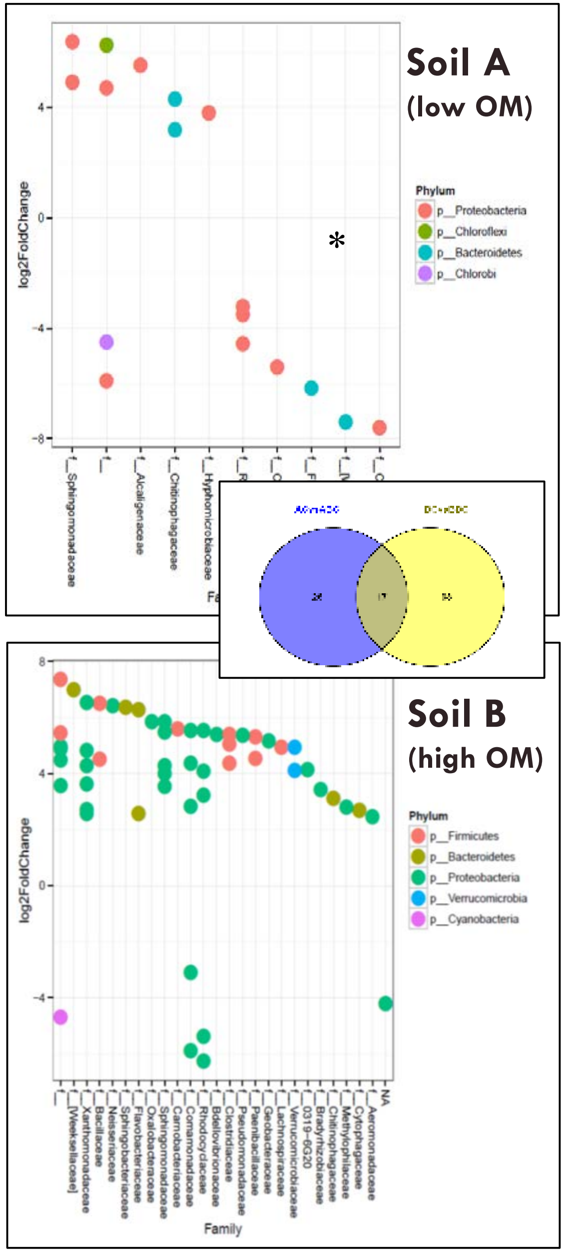
- Greenhouse trials
  - several trials with naturally infested field soils
  - 1 locally available vermicompost amendment
  - 2 commercially-available biochar amendments

RESULTS

- Vermicompost only suppressed *P. capsici* in the low OM soil
- Biochar suppressive activity was greater in the high OM soil
- Suppressive activity correlated with change in pepper rhizosphere microbial community structure



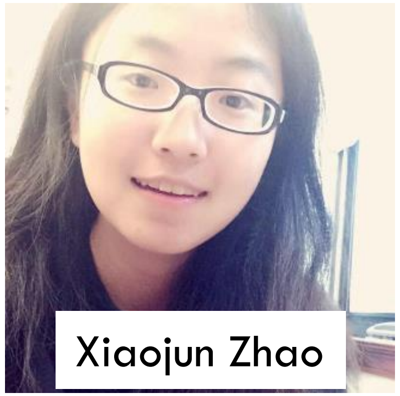




(Shoaf et al., 2016; Hoagland et al., in prep)

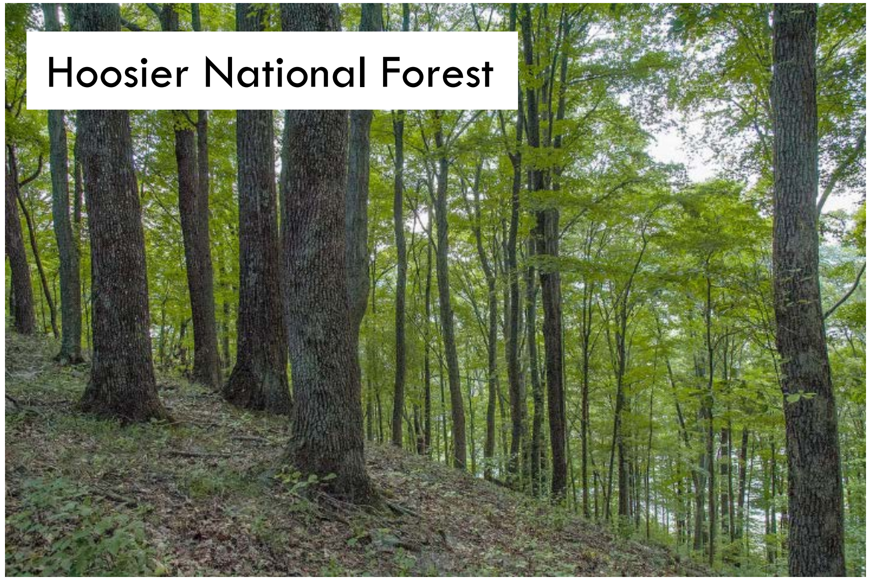
Change in pepper rhizosphere community structure with biochar

BIOCONTROL OF PHYTOPTHORA BLIGHT WITH FOREST INDUSTRY RESIDUALS



(Zhao et al., in prep)

- Alternatives to biochar
- Greenhouse trials
  - 2 naturally infested field soils amended with <u>*additional P. capsici inoculum*</u>
  - Wood flour, kraft pine lignin, woody compost and two wood-based biochars – <u>*all at 2 rates*</u>
- Results-to-date
  - Biochars suppressed *P. capsici* at high rate only
  - WF (low rate), KPL (high rate) and WC (high rate) were as effective wood-based biochars
  - Suppressive activity correlated with increased microbial diversity and fungal:bacterial ratio



Wood flour

(oak, maple, & ash; Fiber By-Products Corp., Goshen, IN)

Wood fines compost

(mixed hardwood spp.; Soilmaker, West Lafayette, IN)

Kraft pine lignin

ndulin AT ®, Westvaco, Co., Charleston, SC)

Biochar

(mixed softwood spp; courtesy North Carolina State

FIELD TRIALS DEMONSTRATING HOW MANAGEMENT PRACTICES CAN AFFECT BIOTIC AND ABIOTIC STRESS

Can benefits be realized in field environments?

LONG-TERM CROP SYSTEMS TRIAL (2011-2015)

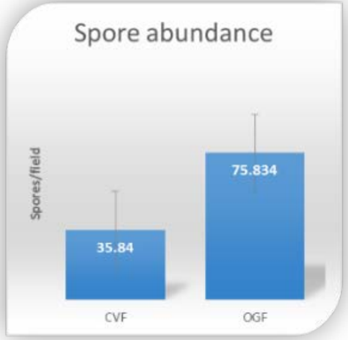
Intensive conventional system	Intensive organic system	Soil-building organic system
- Inorganic fertilizers - *Soil health declined*	- Winter cover crop - Organic fertilizer - *Soil health improved slowly*	- Winter cover crop - Organic fertilizer - Cash crop alternates with summer cover crop - *Soil health improved rapidly*

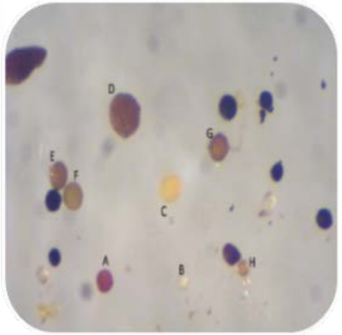
- ***What if we impose stress?***

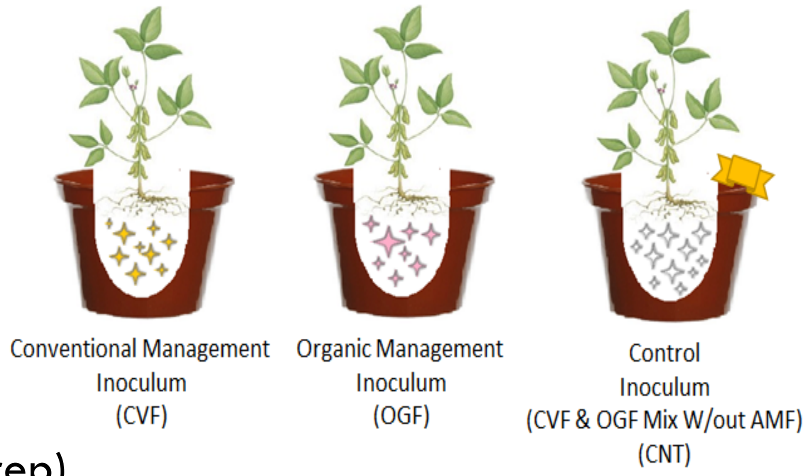
- Cash crop rotation: popcorn, soybean, tomato, and carrot
- ***Few differences in yield***

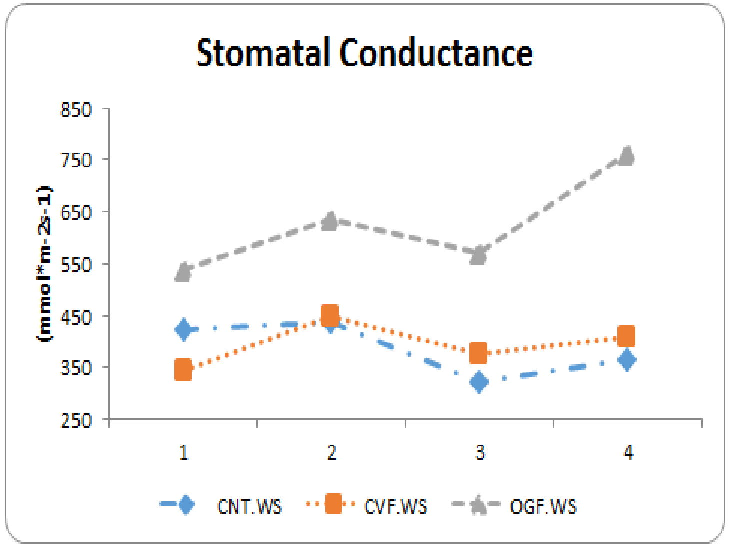
ARBUSCULAR MYCORRHIZAL FUNGI (AMF)

- Symbiotic relationship between plants and certain fungi
- AMF were more abundant and diverse in the organic system
- Greenhouse trial to determine if these differences would affect drought stress
- Results: plants grown with AMF inoculum from the organic system had greater drought tolerance and higher yield



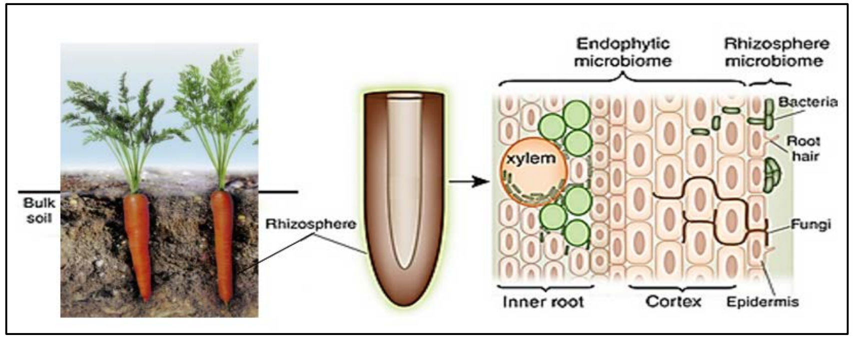


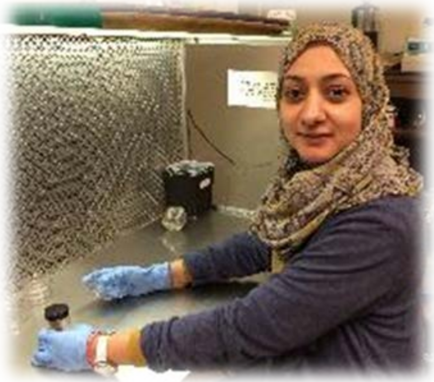




(Zubieta et al., 2015; Zubieta et al. in prep)

CARROT ROOT ENDOPHYTES





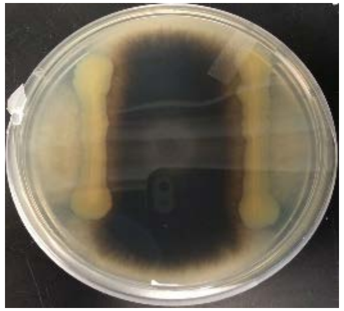
Sahar Abdelrazek

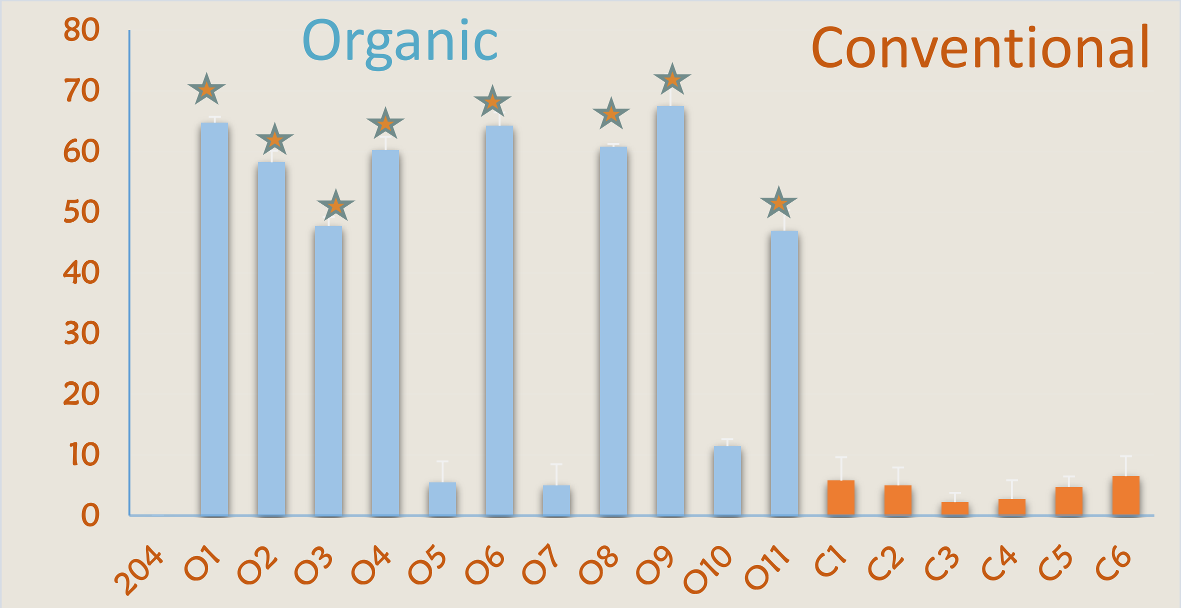
- Understudied microbes that live inside plant roots
- Endophytes in carrots were more abundant and diverse in the organic system
- Endophytes from organic system were more suppressive to Alternaria blight (*Alternaria dauci*)

Alternaria dauci

Antibiosis

NO Antibiosis





(Abdelrazek et al., in prep)

HIGH TUNNEL SOIL MANAGEMENT TRIAL (2011-2014)

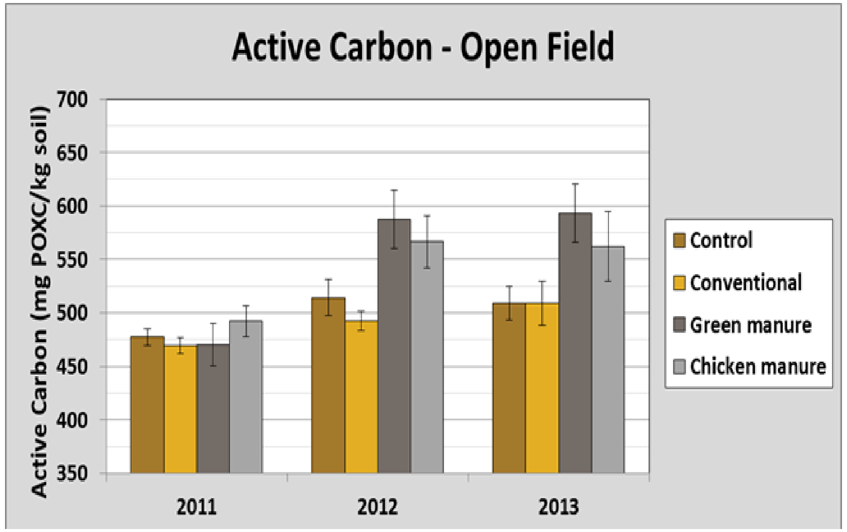
- Extend growing season, increase crop yield, reduce some pests
- Intensively managed (heavy foot traffic, multiple crops/growing season, high nutrient needs)
- High evapotranspiration and limiting leaching events
- Limited crop rotation

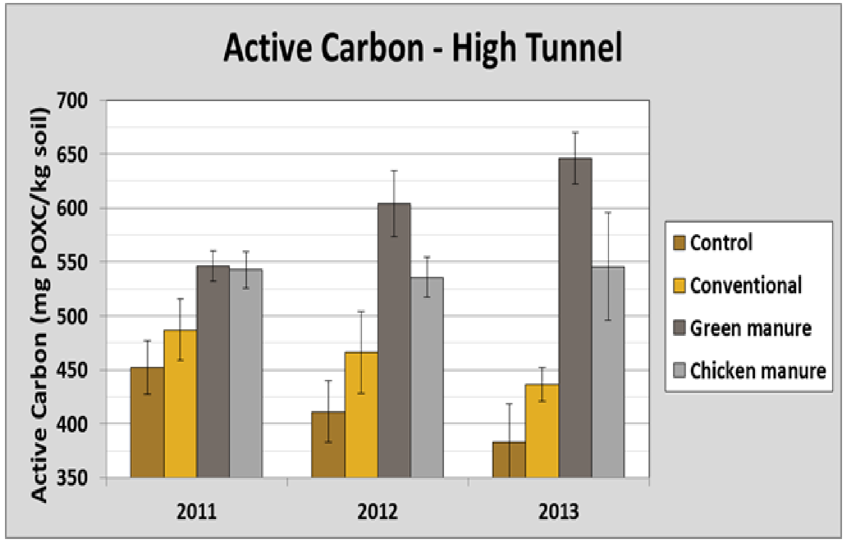
Treatments: Control (no amendment), Urea, Chicken Manure, Green Manure (vetch/alfalfa)

RESULTS

- Soil quality declined in urea and control treatments in high tunnel
- Green manure treatment improved soil healthin both systems
- Soil EC higher in high tunnel regardless of treatment
- Pepper yield greater in high tunnel, but not affected by amendment

- ***What if we introduce crop stress?***



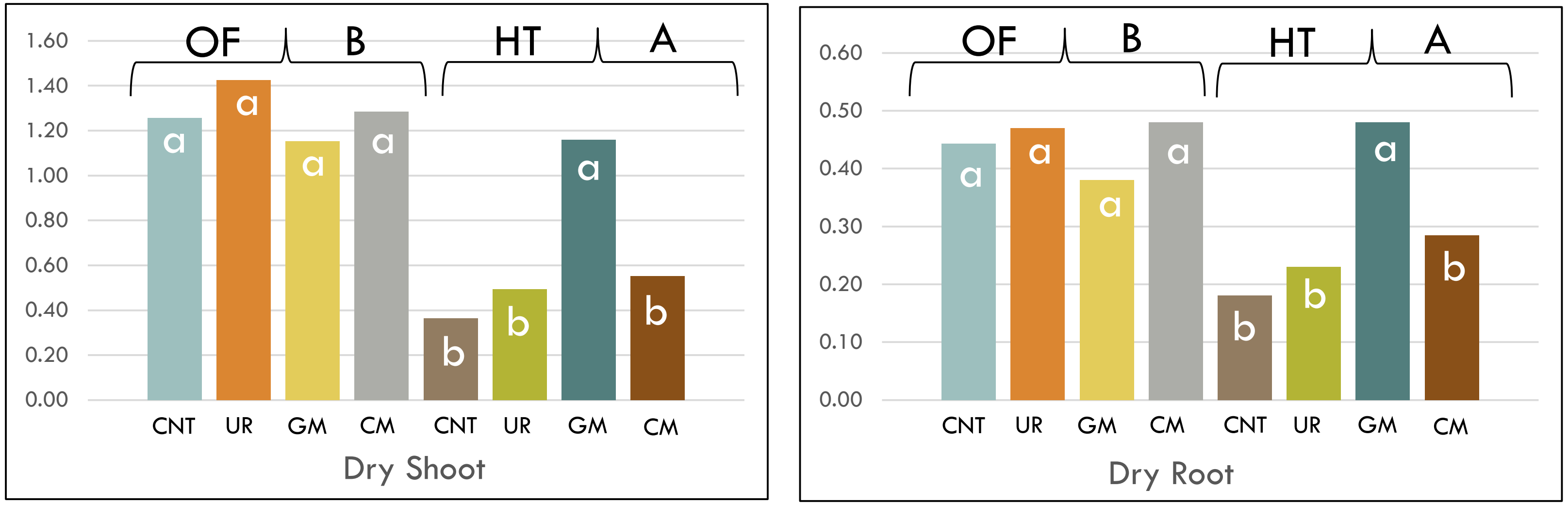


(Rudisill et al., 2015; Rudisill et al., 2016)

BIOASSAYS WITH SNAP BEAN AND *RHIZOCTONIA SOLANI*

(Gomez et al. in prep)

- Dramatic reduction in health of plants grown in soil from high tunnel relative to open field system
- Green manure mitigated negative impact of high tunnel
- Negative effects eliminated with soil sterilization -> ***biologically mediated***

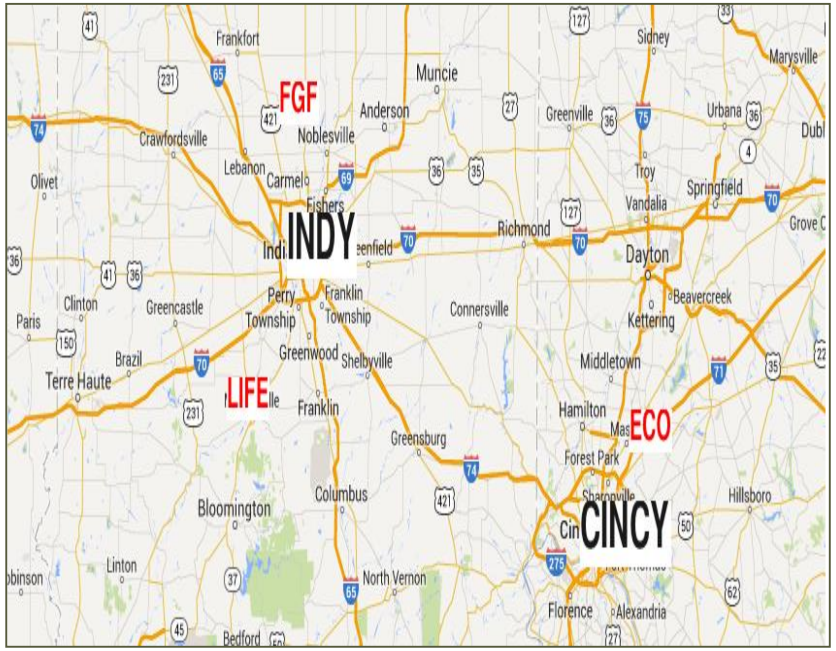


- Distinct changes in snap bean rhizosphere community structure
  - ***Actinomycetes greater in green manure***
  - ***Enterobactereacea greater in urea***

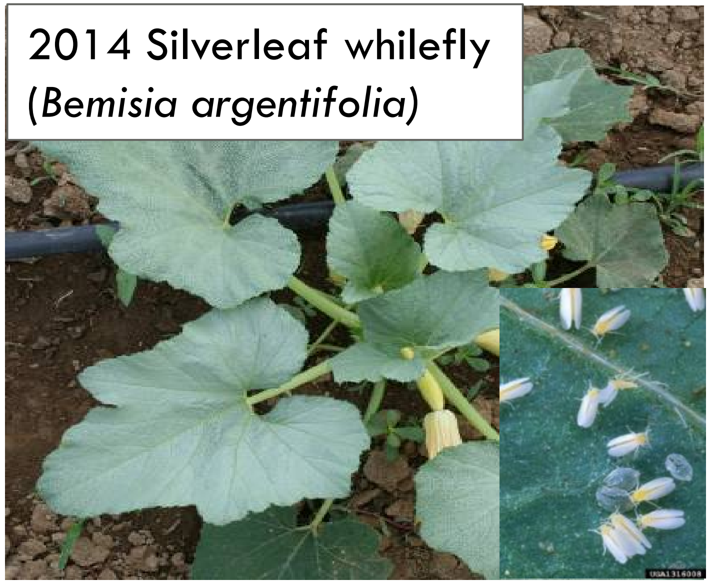
ON-FARM ORGANIC FERTILITY AMENDMENT TRIAL (2013-2015)

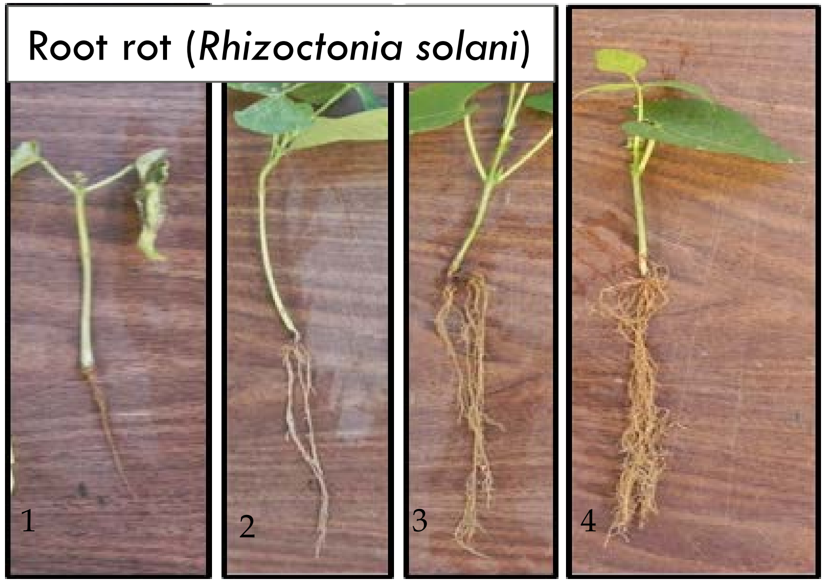
- Three vegetable farms
- Four commercially available fertility amendments
  - partially composted chicken litter (PCCL)
  - plant byproducts
  - animal and plant byproducts
  - vermicompost + PCCL
- <u>Crop rotation</u>: cabbage, acorn squash, tomato
- Winter cover crop on all treatments
- Nitrogen release, soil health, ***pest incidence and severity***, and crop productivity

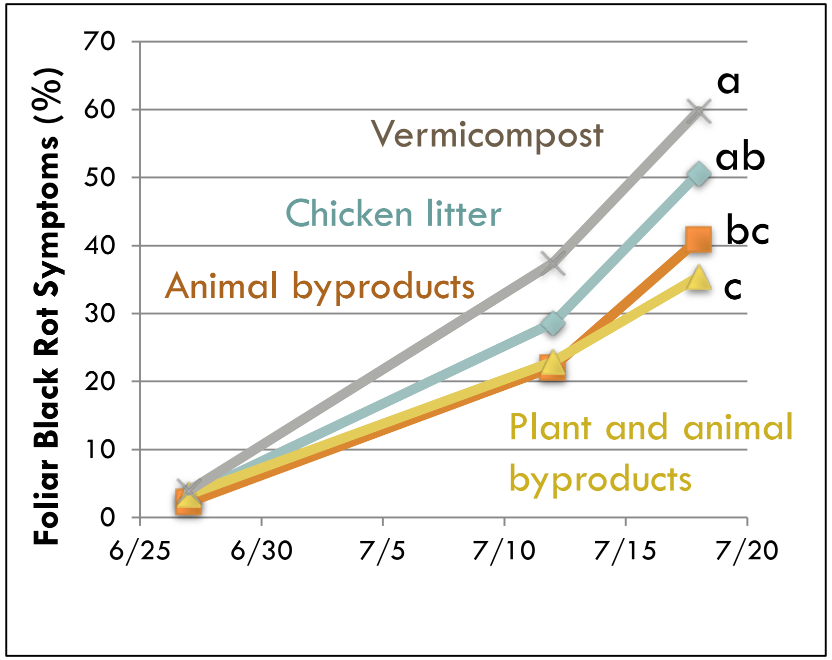
Natasha Cerruti

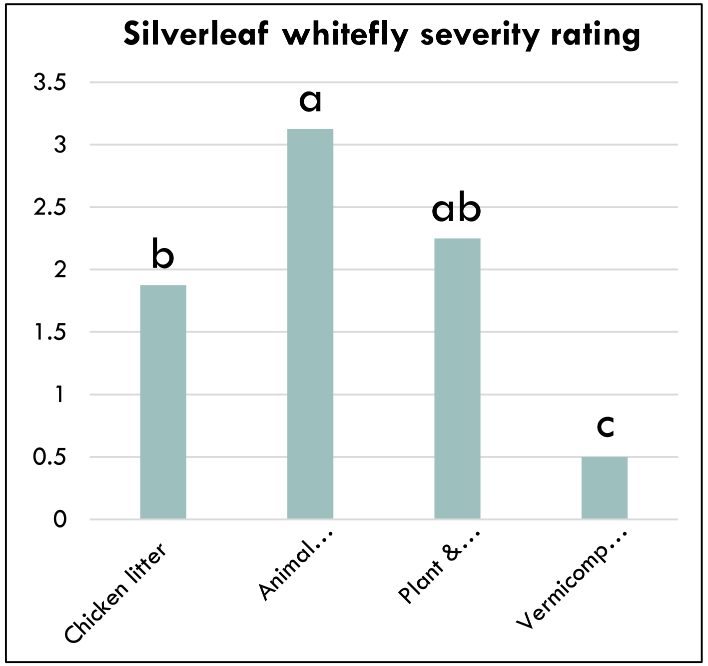


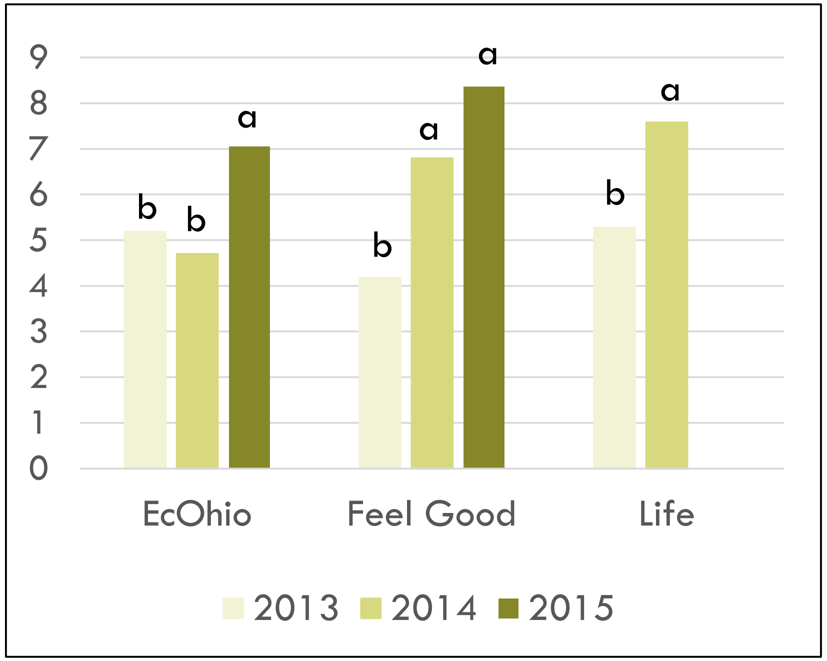
(Hoagland et al., 2014)











Potential correlation with N availability

Not correlated with N availability

Biologically mediated

CONCLUSIONS

- The health of the soil can affect pest outbreaks and greater soil health could increase yields and reduce pesticide costs
- Suppressive activity often correlated with distinct changes in soil microbial community structure
- Cover crops and organic soil amendments can induce suppressive activity, but results depend on soil and amendment composition
- On-farm research trials recommended
- Common soil quality tests (ie. *labile carbon* and *microbial activity*) often correlated with suppressive activity and useful for on-farm trials

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Specialty Crop Production Systems Lab

QUESTIONS?