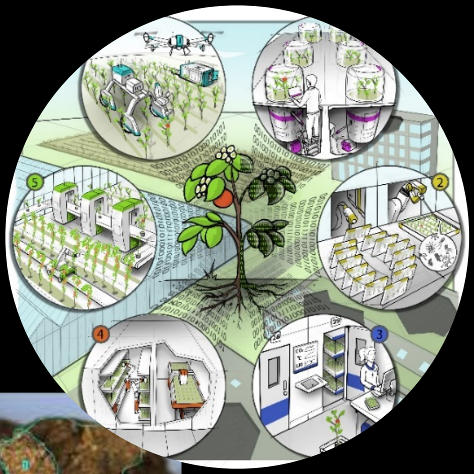
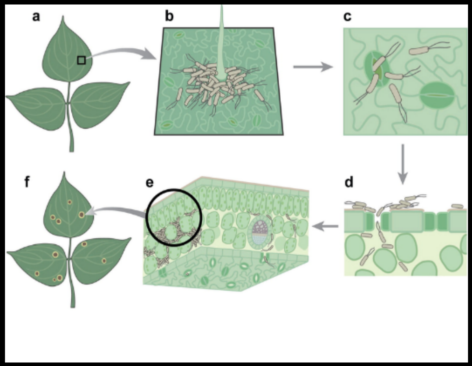
Using ecological rules to help tame the soil microbiome



George A. Kowalchuk

Universiteit Utrecht

Ecology & Biodiversity: Inst. Environmental Biology



November 12th, 2019

FINAL CONFERENCE: BIODIVERSA 2015-2016 CALL

What I plan to talk about

- The need to harness the power of plant-microbe interactions
- Plant abilities to cultivate a functional microbiome
- Defining the rules of rhizosphere microbiome community assembly

Acknowledgements

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Nederlandse Organisatie voor Wetenschappelijk Onderzoek

The Green Revolution

The increase in food production, especially in developing nations, through the introduction of **high-yield crop varieties** and application of **modern agricultural techniques**

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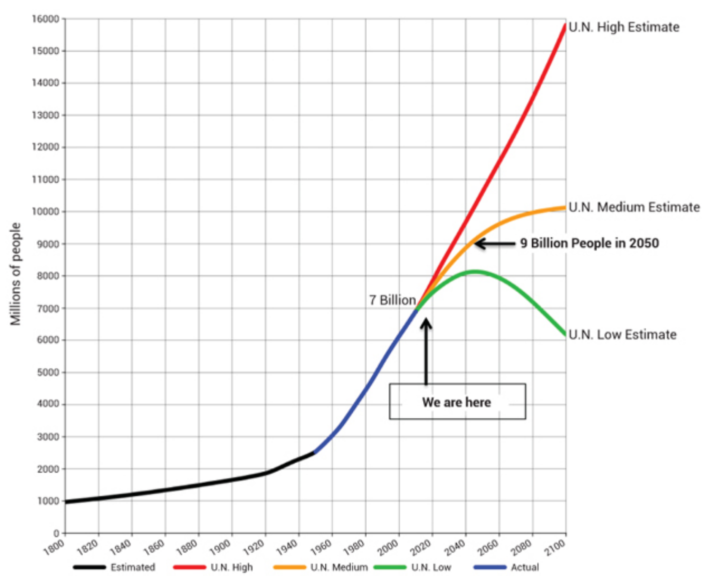
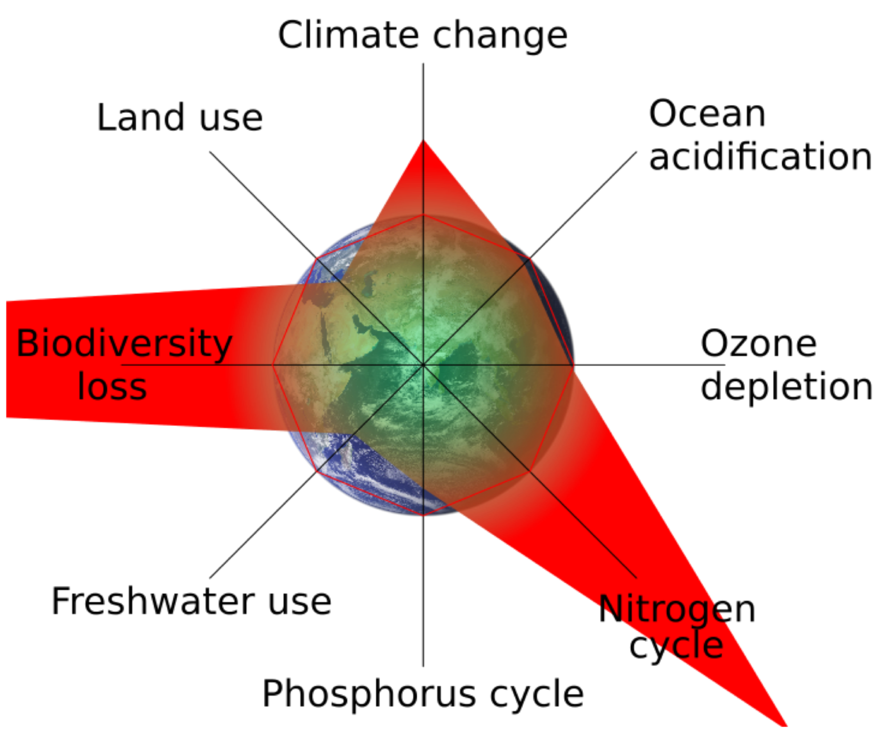
The green revolution allows us to live beyond our means





Steffen et al Science (2015)

Current agricultural practices are not sustainable

- High amounts of energy (and water) input
- Further disruption of Earth’s nutrient balance (especially for Nitrogen)
- Reliance on depleting Phosphate reserves (probably less than 50 years)
- Depletion of soil fertility & soil degradation
- Loss of biodiversity

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Mankind's grand challenge

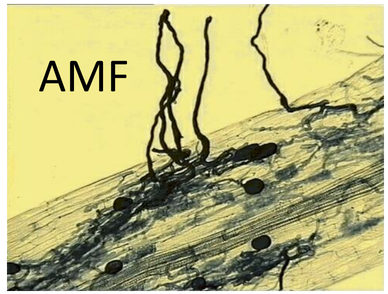
How do we feed the planet without destroying it?

- preserving soils
- **using plant-microbe interactions**
- unlocking the genetics of plants

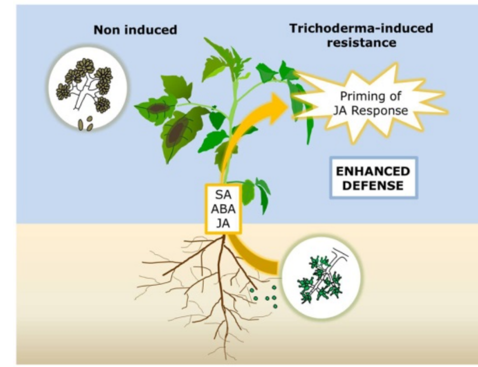
2nd green revolution

Unlocking the power of plant-microbe interactions

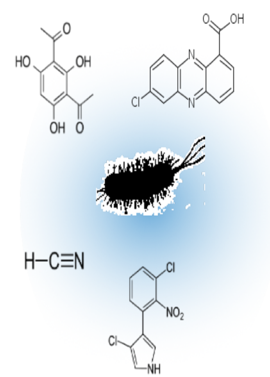
Nutrient uptake



Helping plants deal with stress



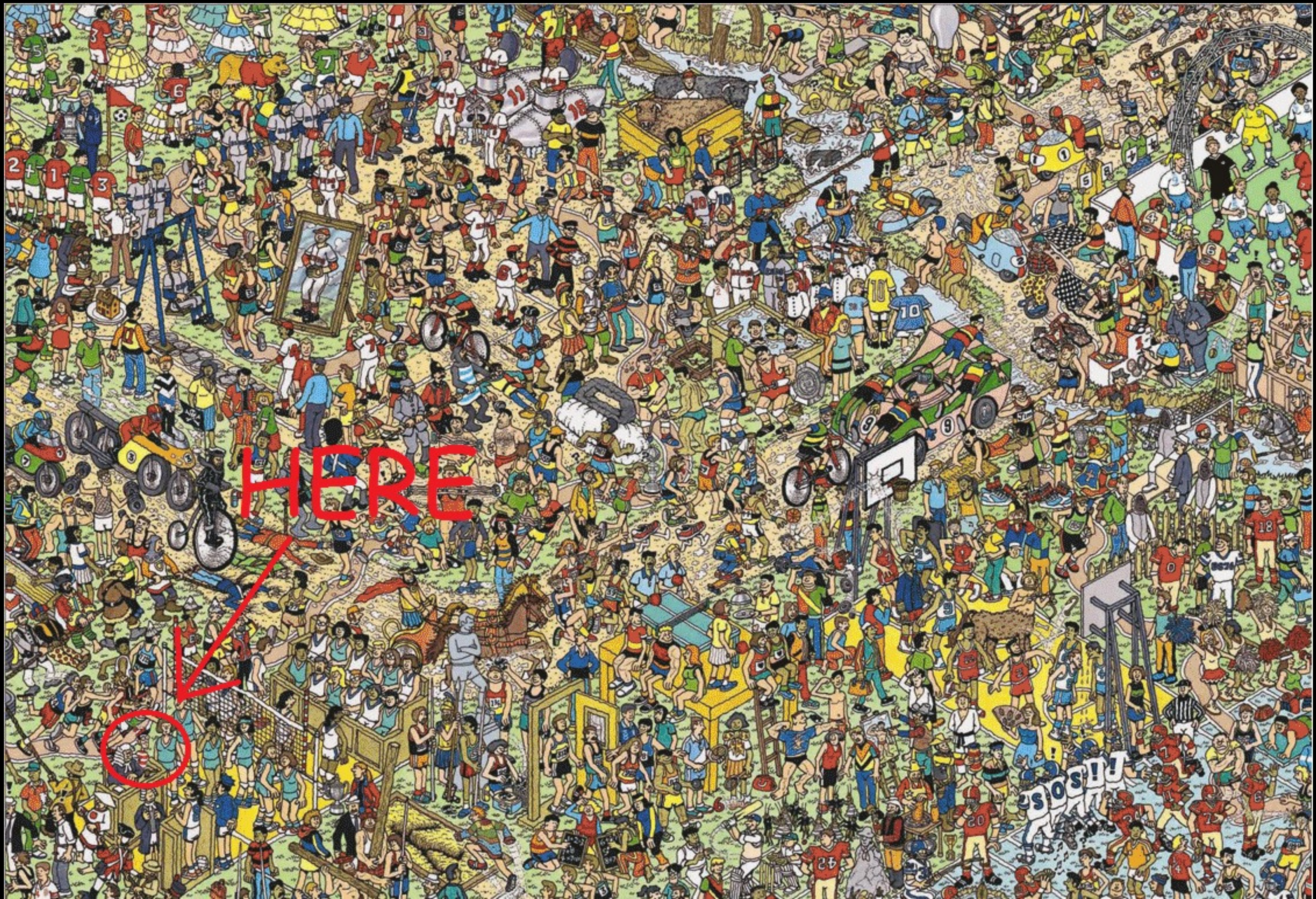
Antagonizing pathogens



Improving soil quality

- Breeding to date has served to eliminate reliance on plant-microbe interactions and foster cheating

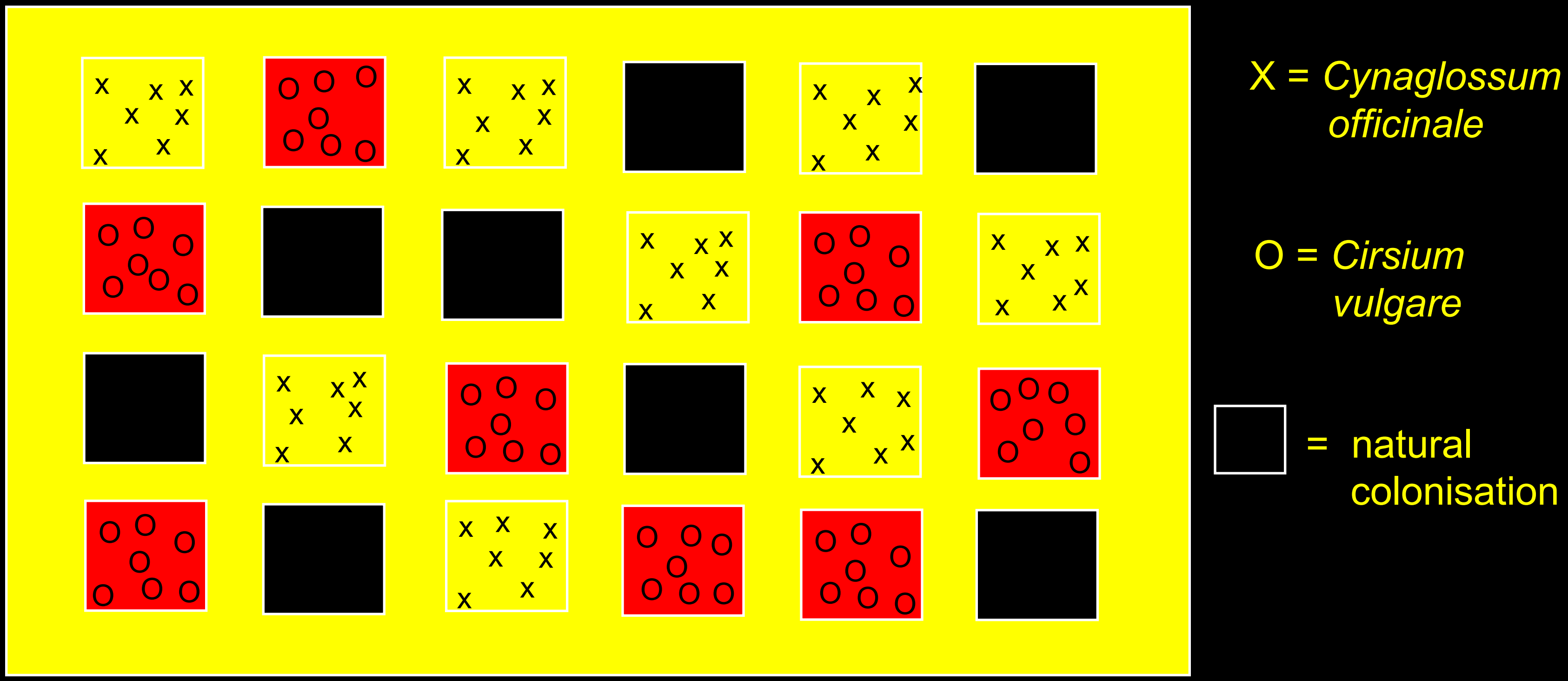
Challenges to taming the soil microbiome



Plants as drivers of their functional microbiome

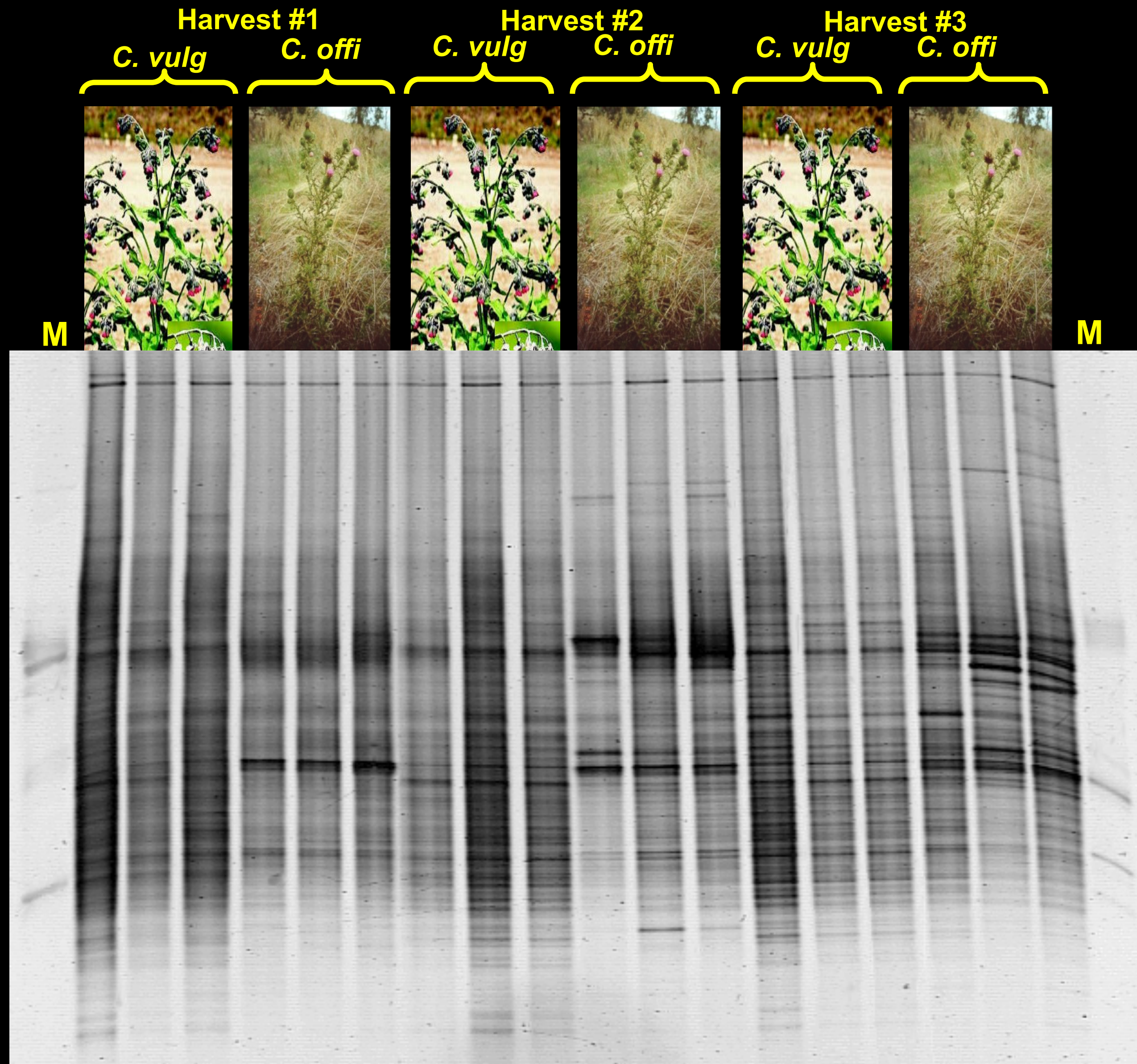
- The plant rhizosphere effect
- Cultivating a beneficial rhizosphere community
- Initial microbiome predicts later health

Experiment to examine rhizosphere effect of specific plant species:



Seven plants per plot (with weeds)
Three harvests times

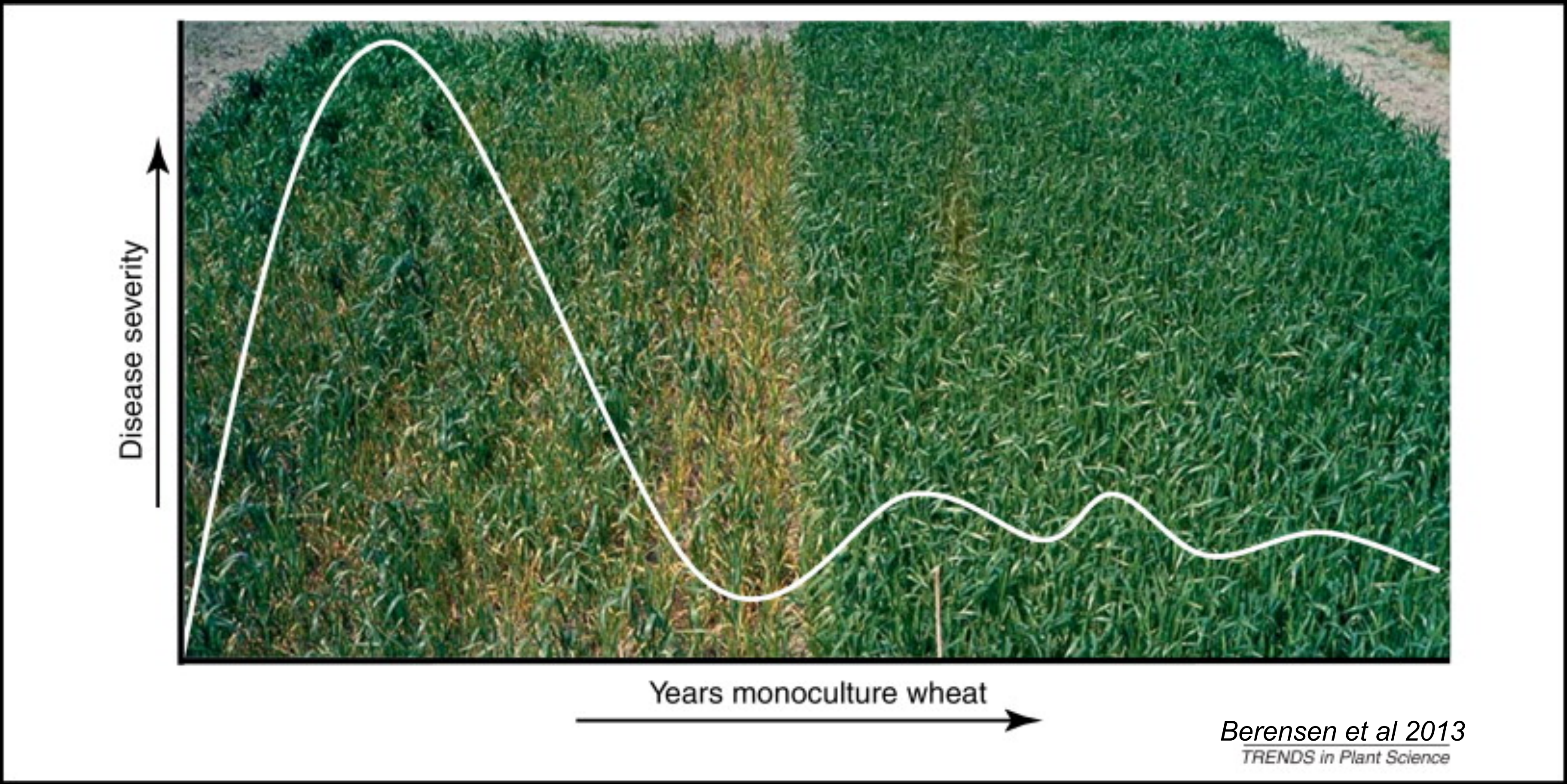
Influence of plant species on rhizosphere communities:



- Plants select for distinct bacterial populations
- Plant-specific patterns maintained over growing season
- All bulk samples look alike
- Sequence ID of dominant bands

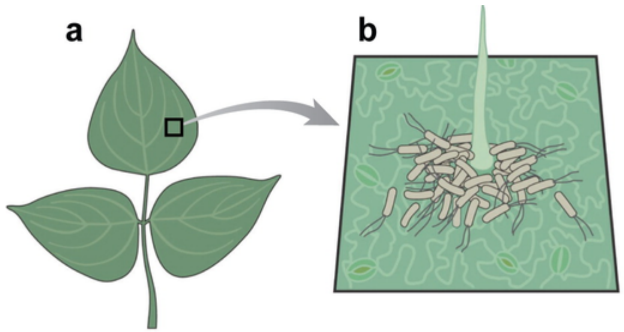
Kowalchuk et al 2002

Cultivating a beneficial rhizosphere community



and soils can be conditioned by growing multiple plant generations

Cultivating beneficial rhizospheres in response to an aboveground pathogen

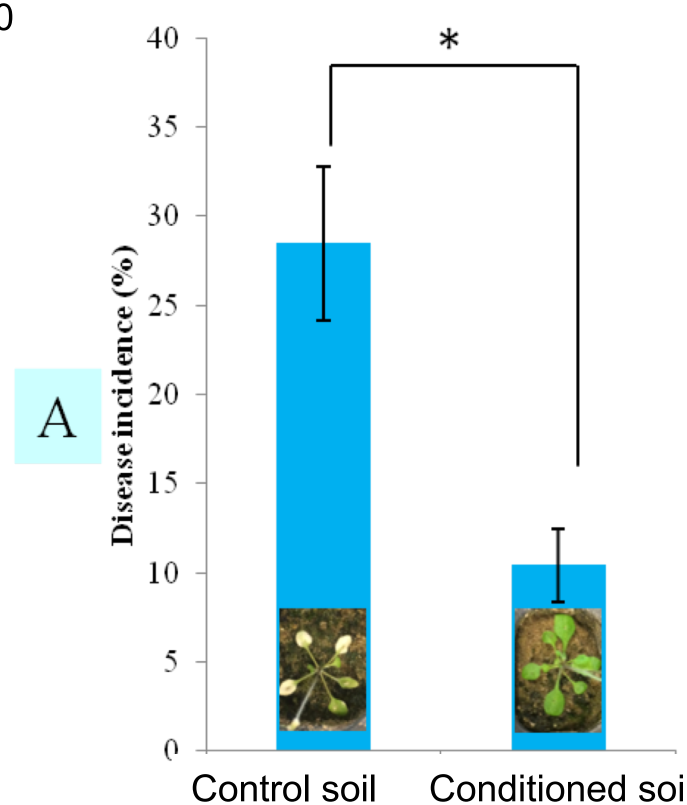


Pseudomonas syringae DC3000

six generations in same soil

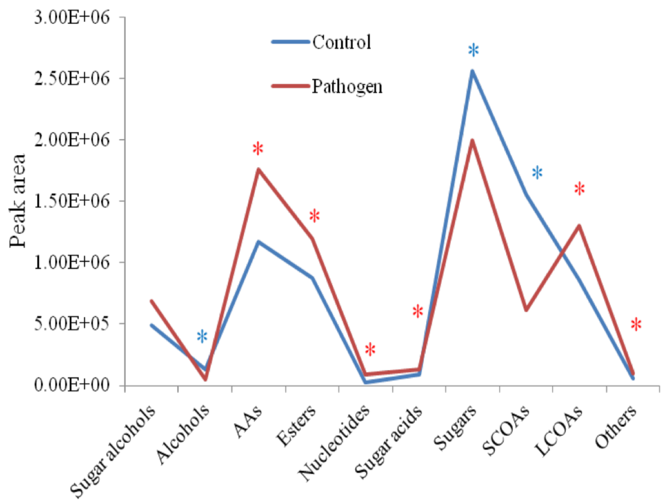
Microbes modulate plant hormones along a stress defense / growth continuum

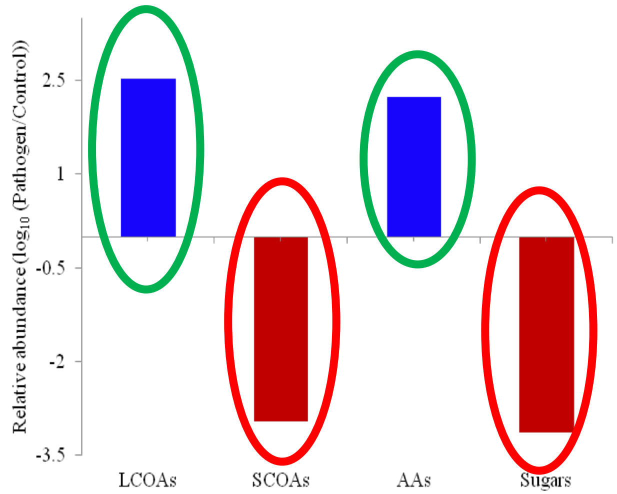
Ravanbakhsh et al ISMEJ 2019



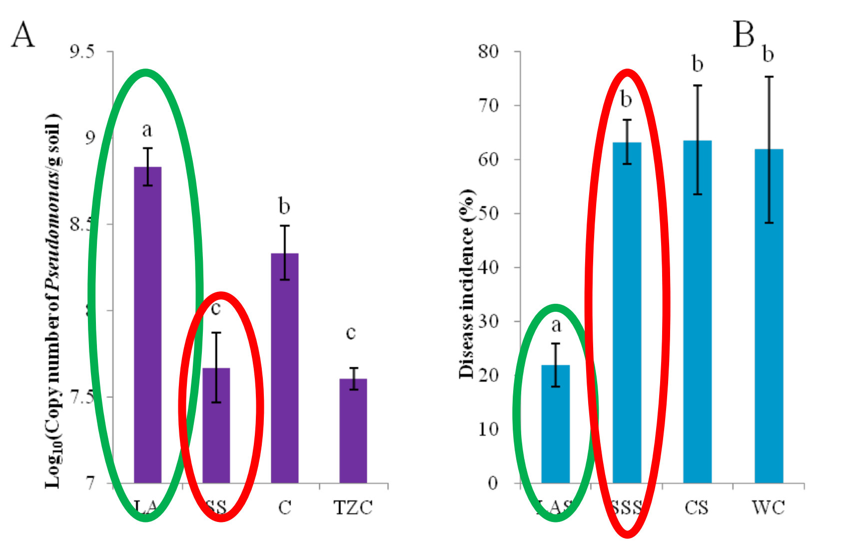
Yuan et al Microbiome (2018)

Cultivating beneficial rhizospheres in response to an aboveground pathogen





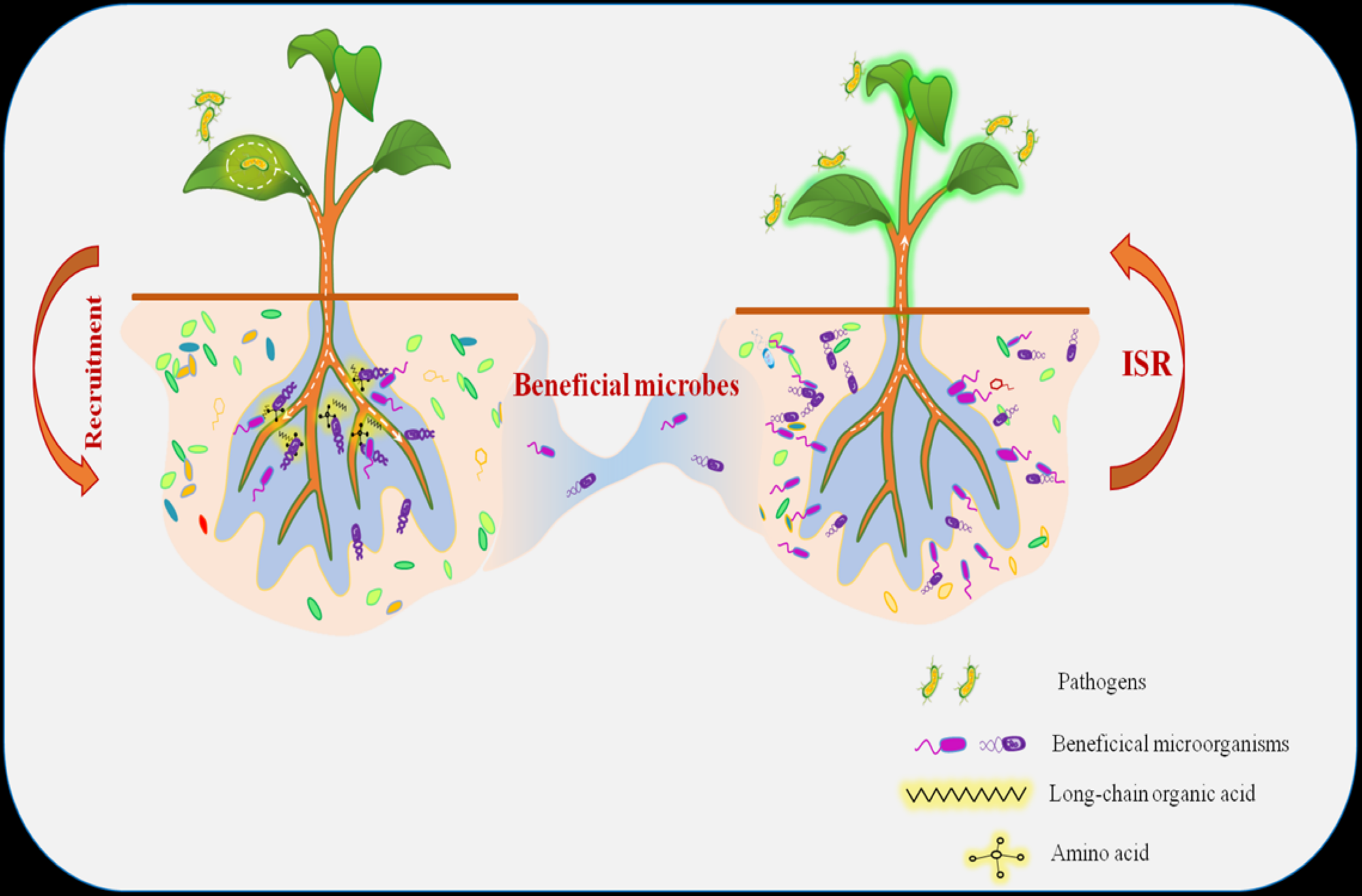
- Pathogen changes exudation patterns



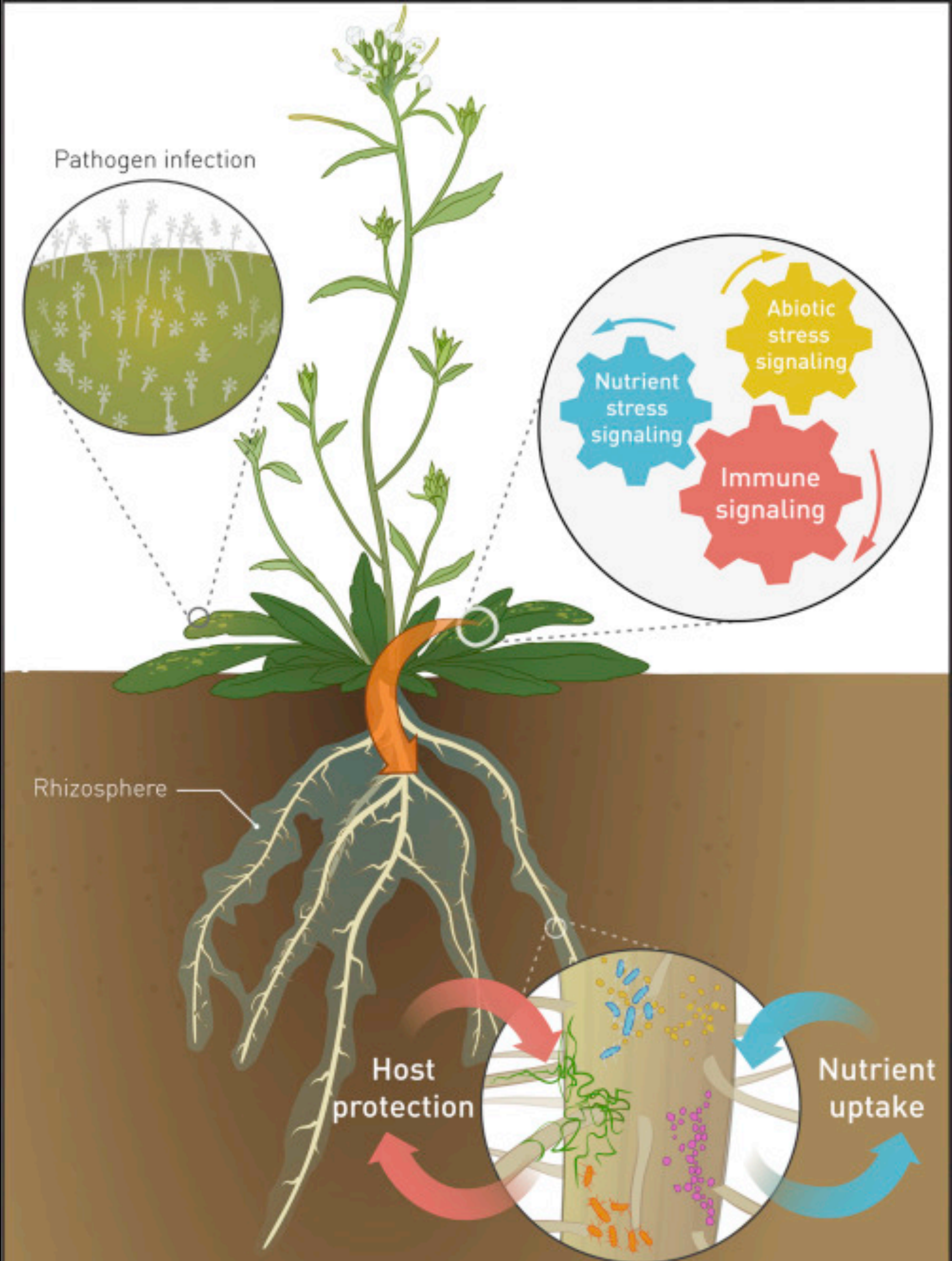
- Long-chain organic acids and amino acids stimulate beneficial pseudomonads

Yuan et al Microbiome (2018)

Soil memory via the microbiome



The Soil-Bourne Legacy



Bakker et al (2018) Cell

Bringing microbial assembly into focus

defining some rules of microbial community assembly

We can borrow concepts from macro-ecology, such as:

Bringing microbial assembly into focus

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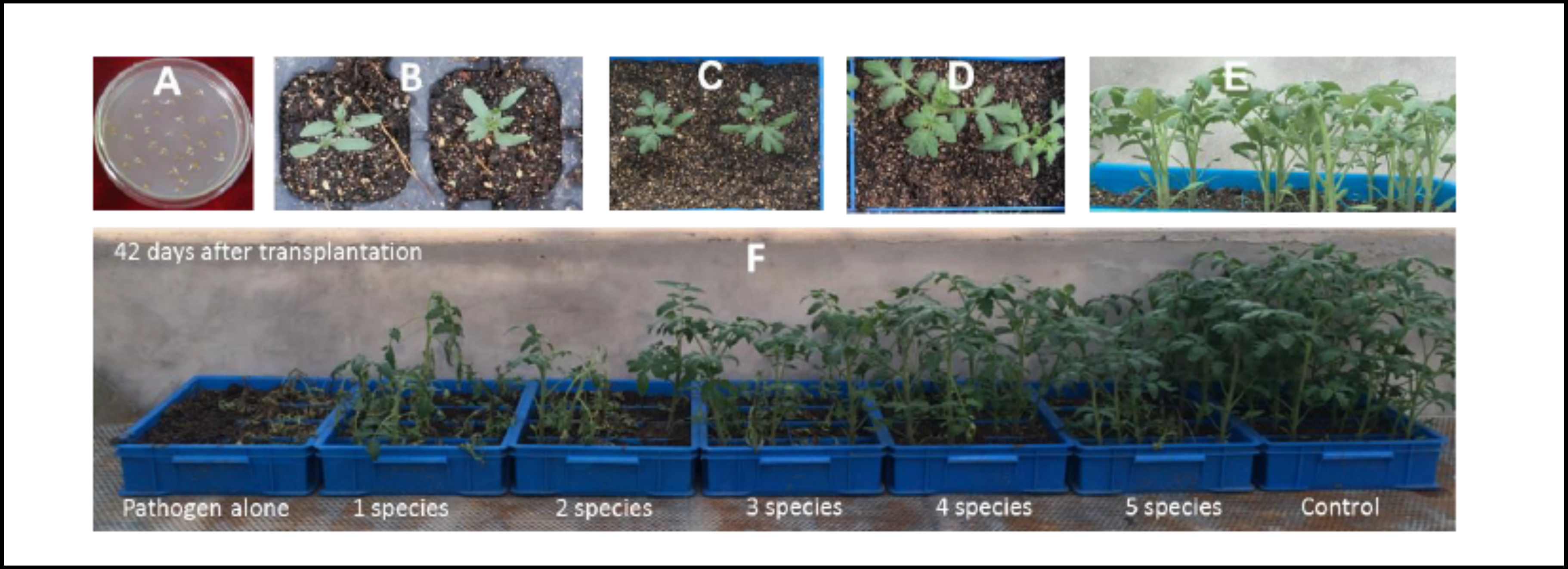
We can borrow concepts from macro-ecology, such as:

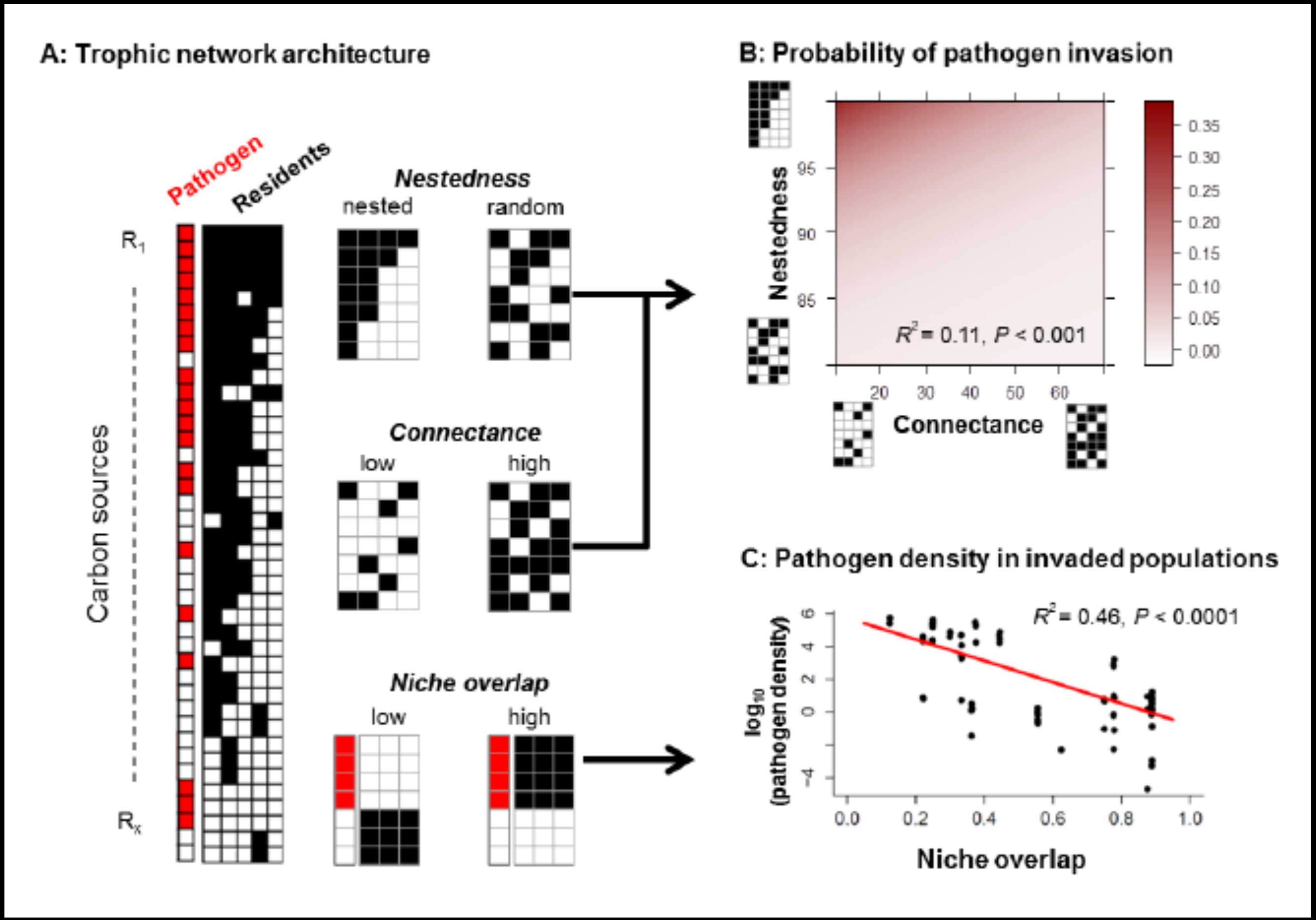
- Priority effects, succession and facilitation
- Niche overlap and competition
- Keystone species
- Trophic interactions
- Habitat connectivity, stochastic processes and neutrality

Multi-species inoculation improves disease resistance



Wei, Yang, et al Nature Comms (2015)

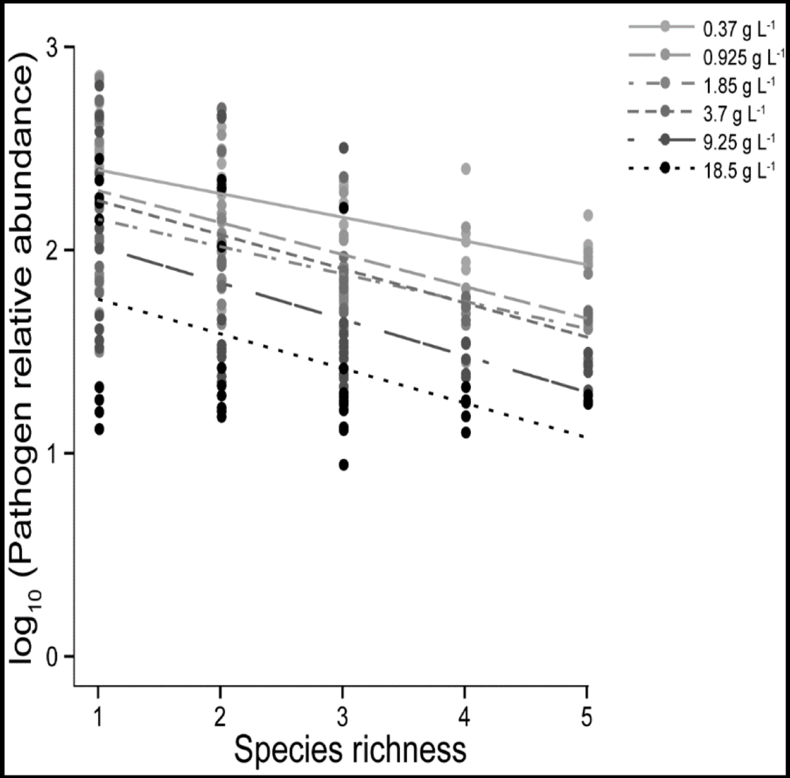
Studying assembly in artificial communities

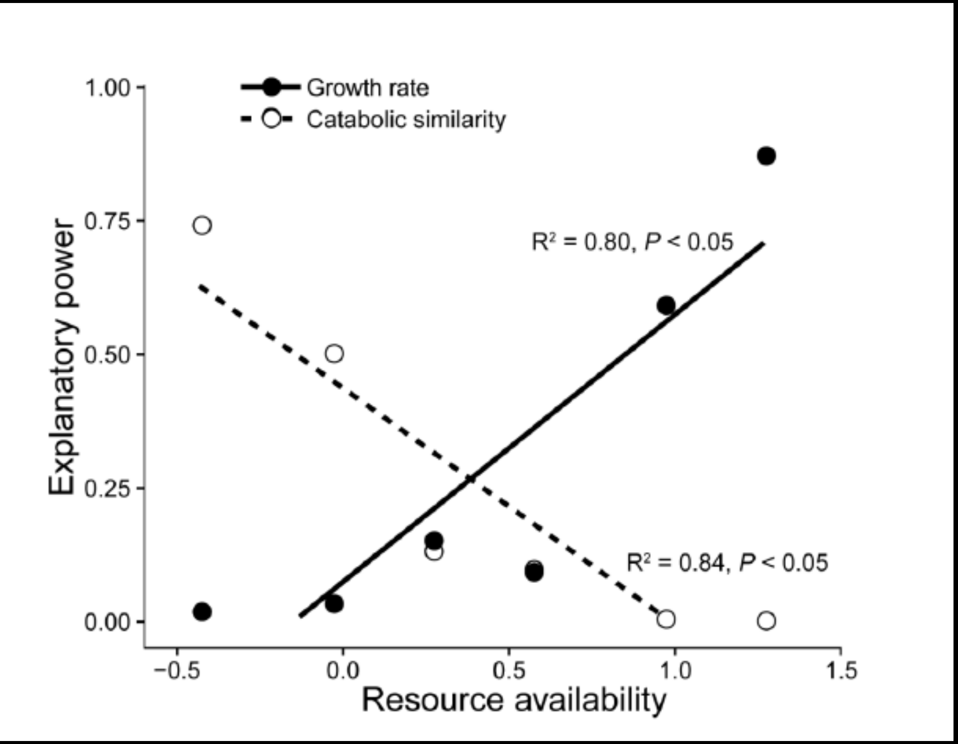


- Communities assembled with defined structure (without direct antagonism)
- Test ability to impede invasion by pathogen
- Population traits predict resistance to invasion

Wei, Yang, et al Nature Comms (2015)

Interactions between species traits and nutrient availability





Diversity / function relationship

Relative disease suppression modulated by nutrient status

High nutrient availability = Growth rate

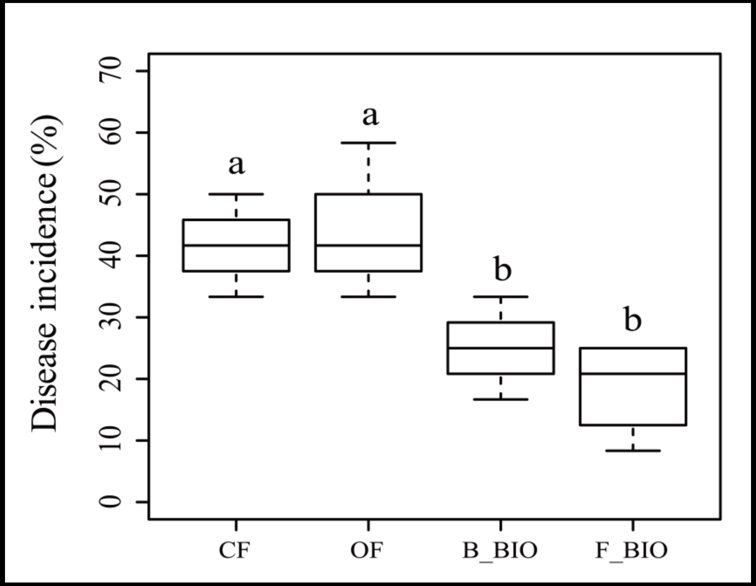
Low nutrient availability = Niche overlap

Yang et al Environ Microbiol. 2017

Impacts of bioorganic fertilizer on soil microbiomes

Goal: Decrease chemical fertilizer use while also reducing disease (Fusarium wilt)

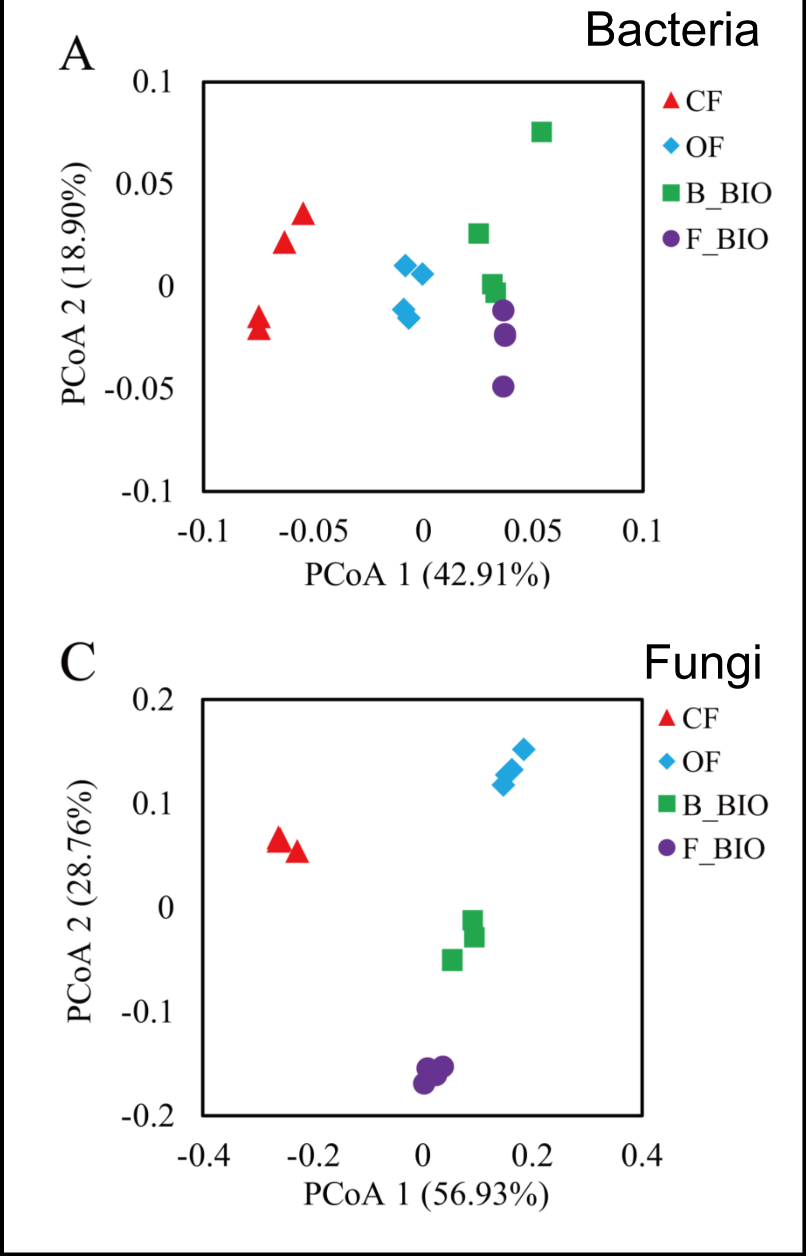
Four treatments:
- Chemical fertilizer (CF)
- Organic fertilizer (OF)
- Bio-organic fertilizer with Bacillus inoculation (B-BIO)
- Bio-organic fertilizer with Trichoderma inoculation (F-BIO)



Wu et al SBB (2017)

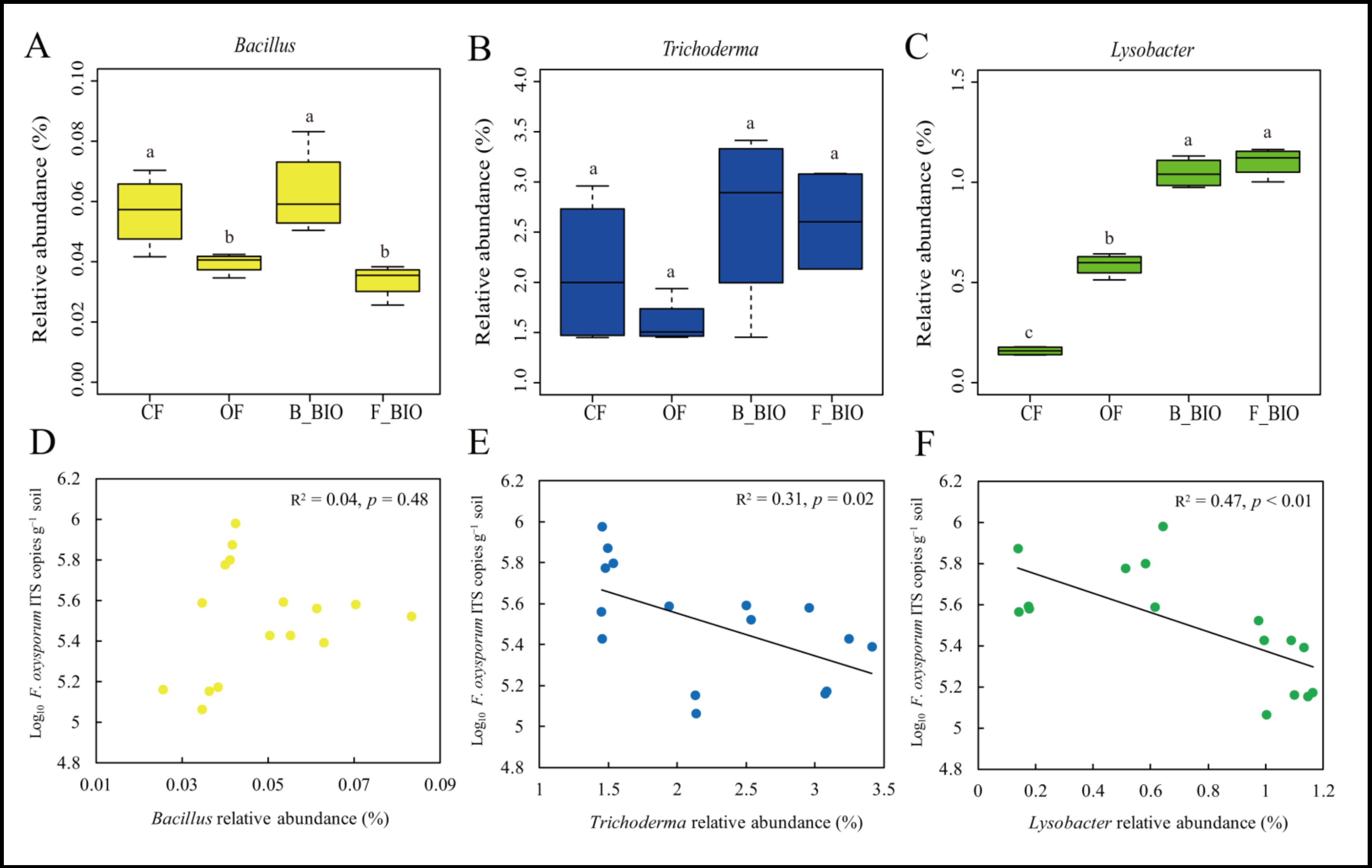
Impact of fertilizer treatment on bacterial & fungal communities

- Bacterial and fungal communities distinct for different fertilizer treatments
- CF treatment most distinct



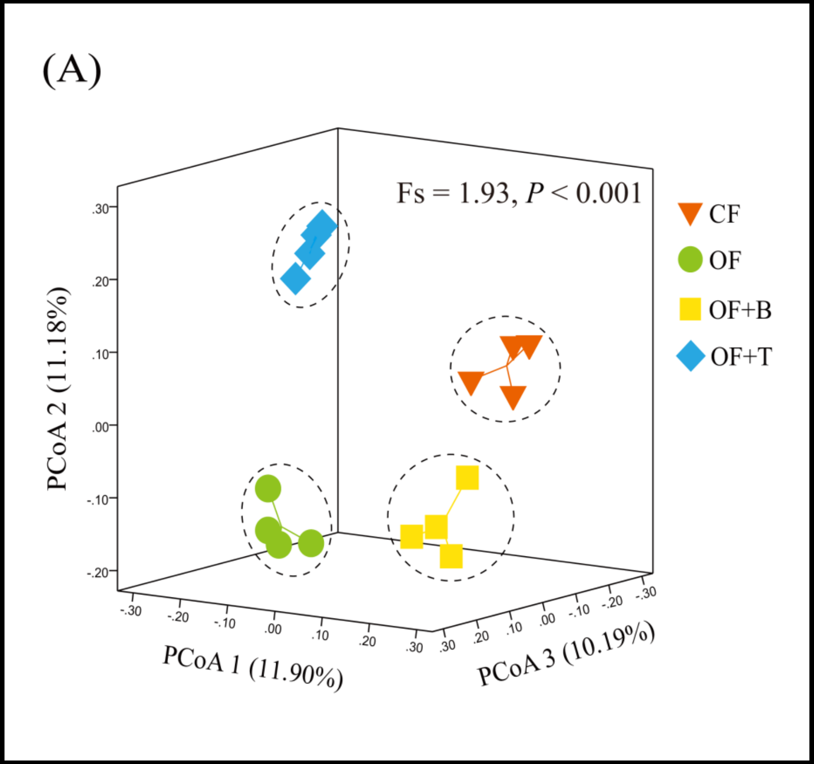
Wu et al SBB (2017)

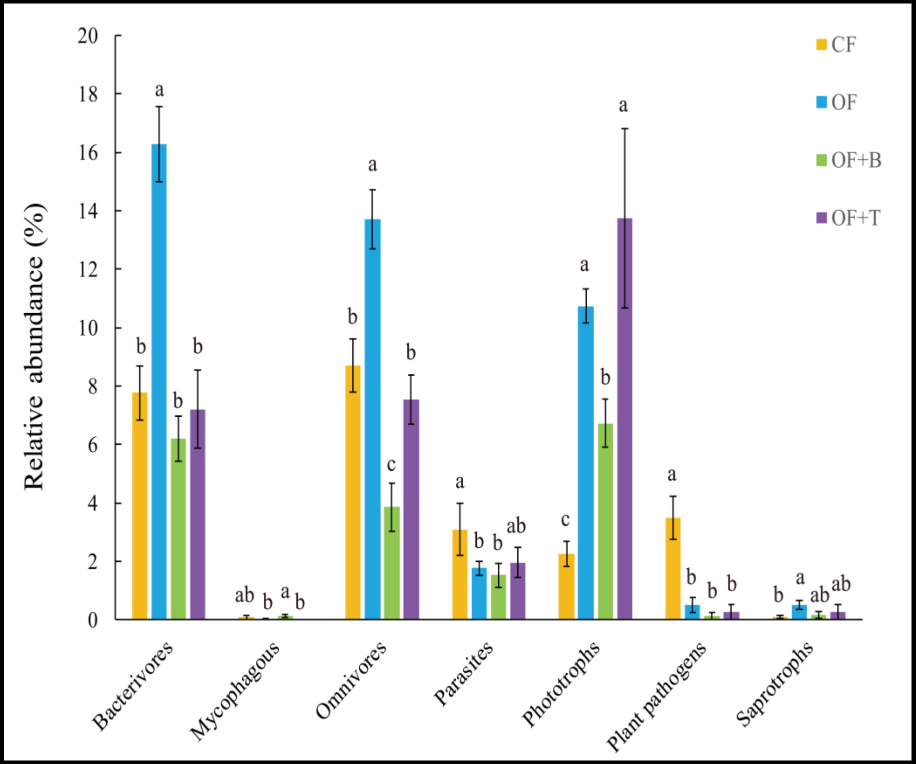
Relation between biocontrol populations and disease-causing agent



Disease suppression not related to density of biocontrol organisms, but rather other stimulated organisms (e.g. *Lysobacter*)

Impact of fertilizer treatment on protist communities



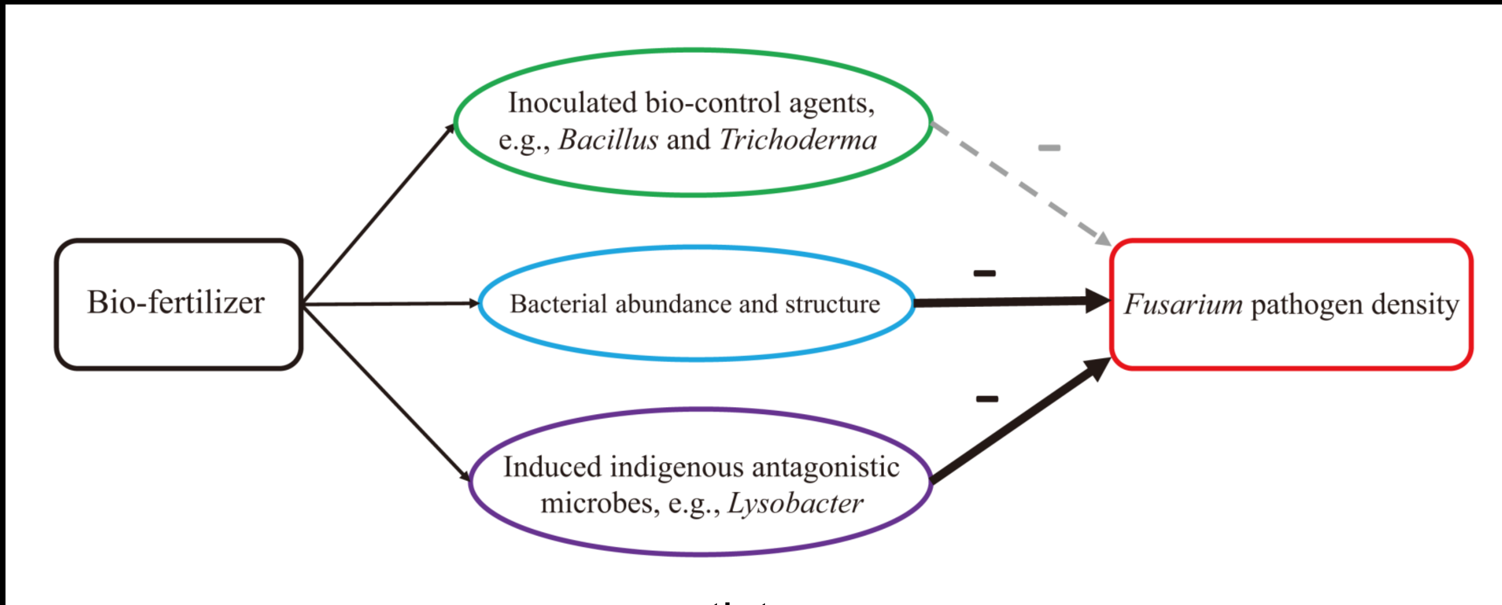


CF treatment more related to pathogens

Others to omnivores, bacterivores & phototrophs

Wu et al ISME Journal (2018)

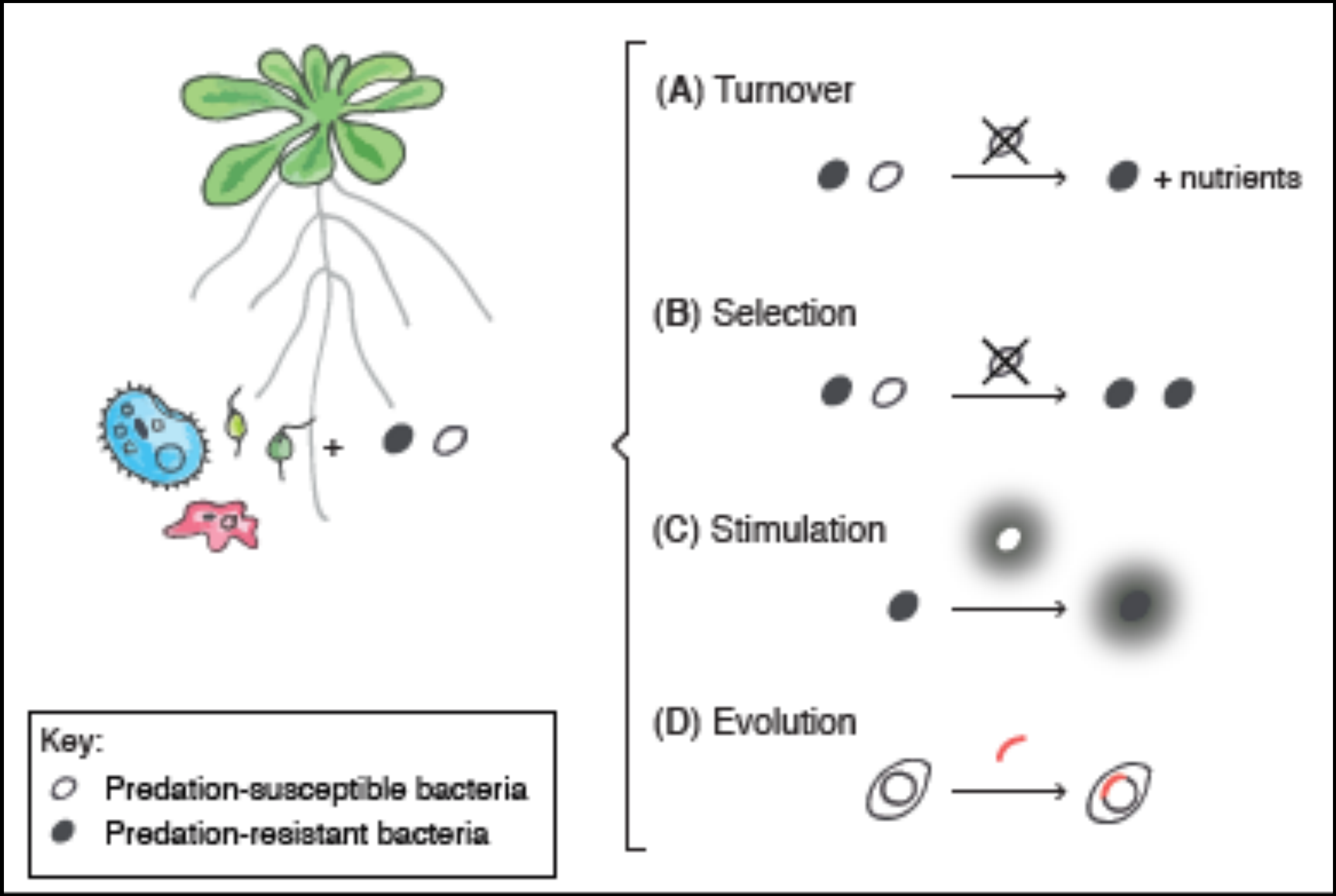
Biological agents act indirectly



- New strategy: develop inocula that activate resident communities
- Protists as dynamic hubs in the soil microbiome
- Increase in negative interactions (soil health = war)

Wu et al ISME Journal (2018); Wu et al SBB (2019)

Utilizing Protists: Puppet masters of the rhizosphere



Gao et al, Trends in Plant Sci. 2018

Bringing microbial assembly into focus

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We can borrow concepts from macro-ecology, such as:

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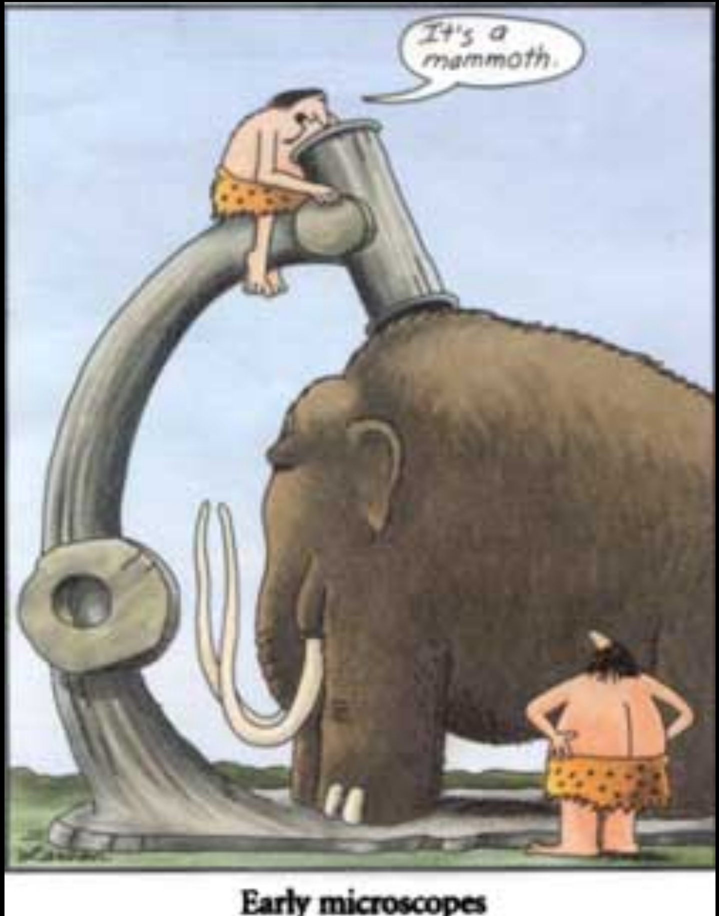
- **Habitat connectivity, stochastic processes and neutrality**

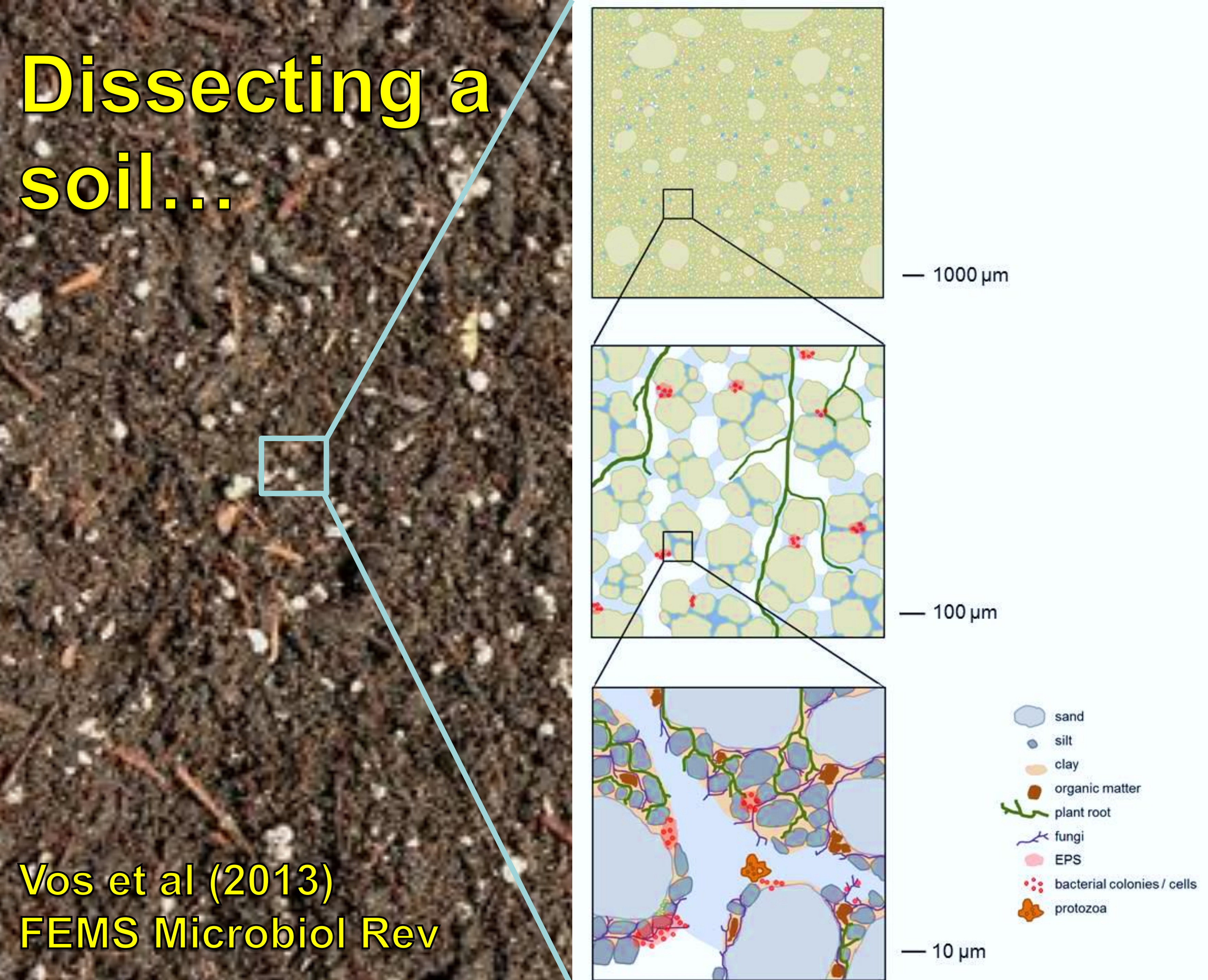
Microbial diversity from a microbial perspective

To date we have generally considered scales of convenience as opposed to those most appropriate to the microbial organisms themselves



Early microscopes

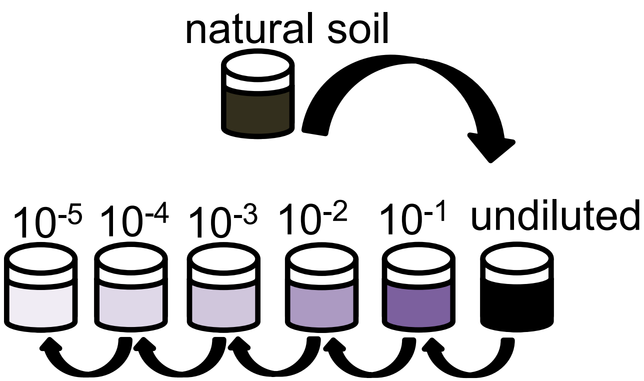
Dissecting a soil...



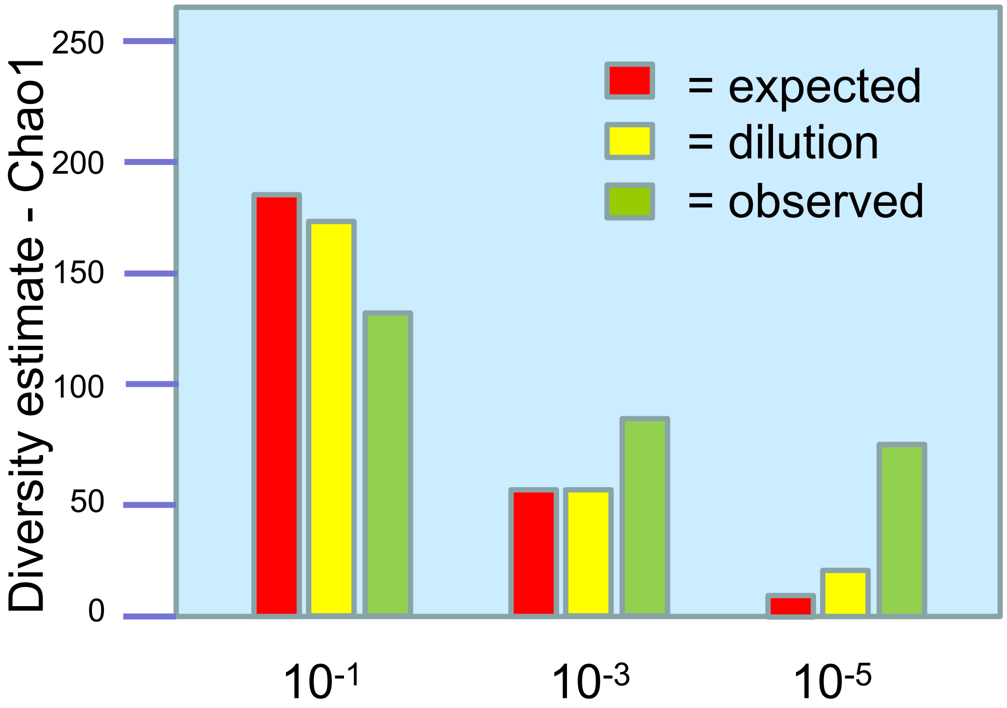
Vos et al (2013)
FEMS Microbiol Rev


Cyst
Amoeba
Flagellate
Bacterial Colonies
Nematode
Ciliate
Clay-Organic Matter Complex
Decomposing Plant Cells
Water
Actinomycete hyph
and Spores
Fungal Hyphae
and Spores

Community assembly after dilution and re-inoculation

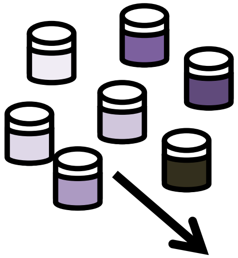


Serial dilution as a means of reducing bacterial diversity to examine diversity/function relationship

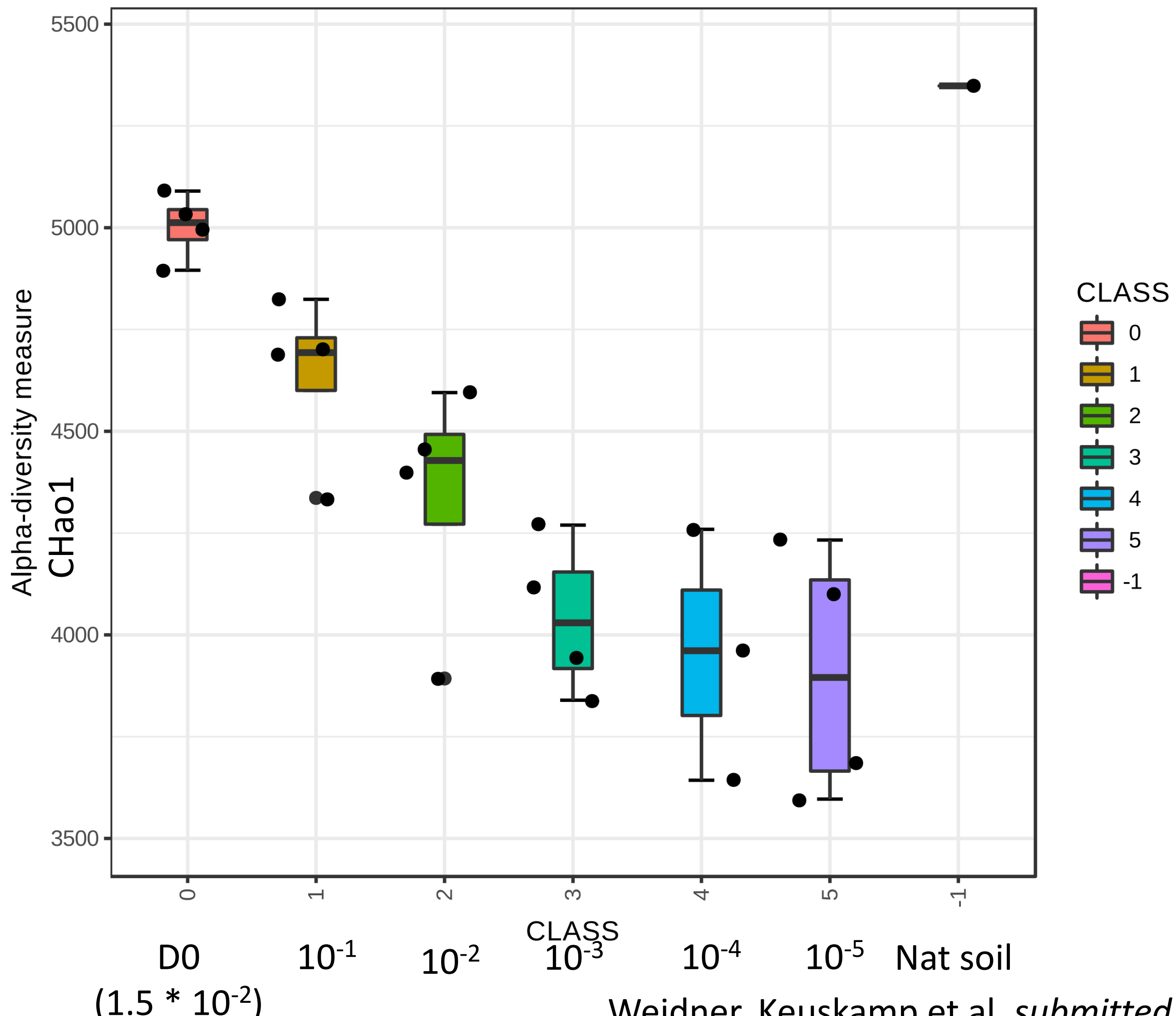


Hol et al Ecol Let 2010; Kuramae et al AEM 2015

Effect of serial dilution on species richness

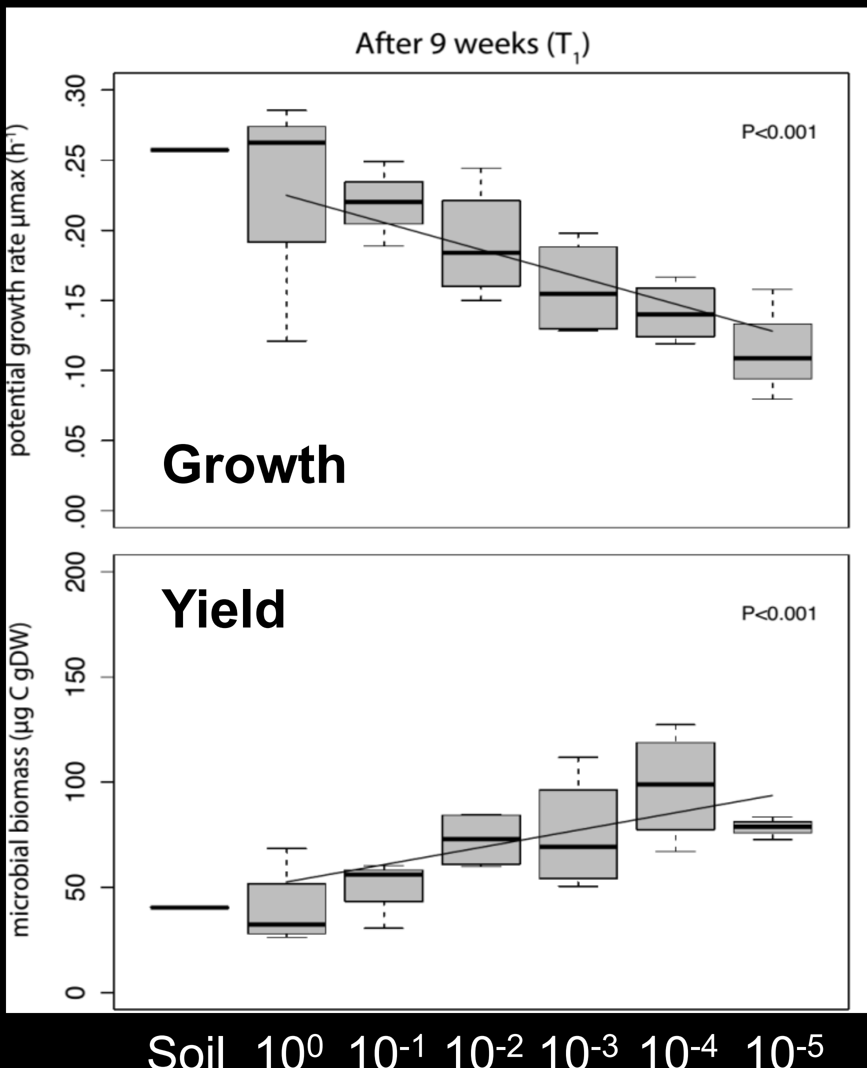


16S rRNA tag sequence data after 9 weeks of incubation



Weidner, Keuskamp et al, *submitted*

Selection of microbial growth strategies upon re-inoculation



Higher dilution selects for:

SLOW GROWTH

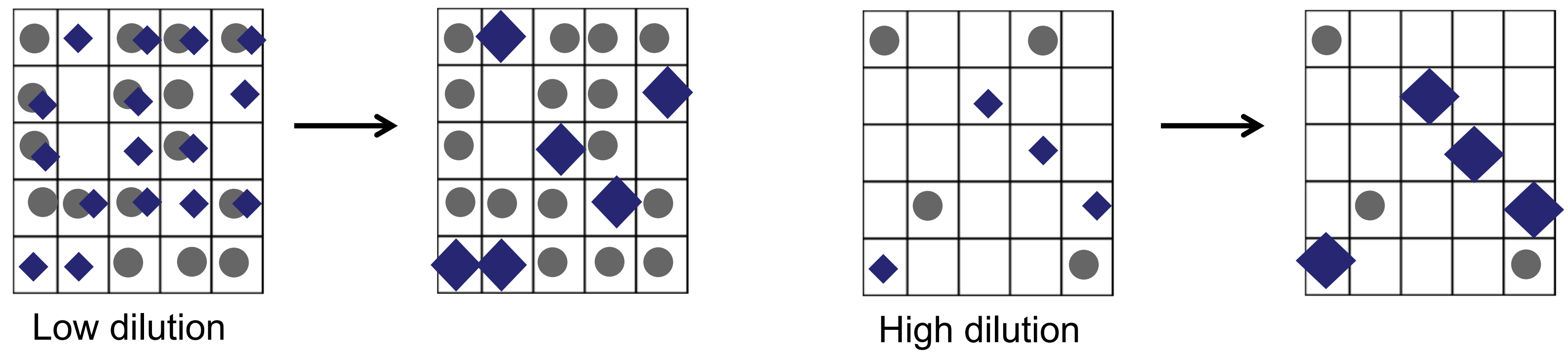
and

HIGH YIELD

Weidner, Keuskamp *et al. submitted*

Spatial distribution and modeling yield versus growth communities

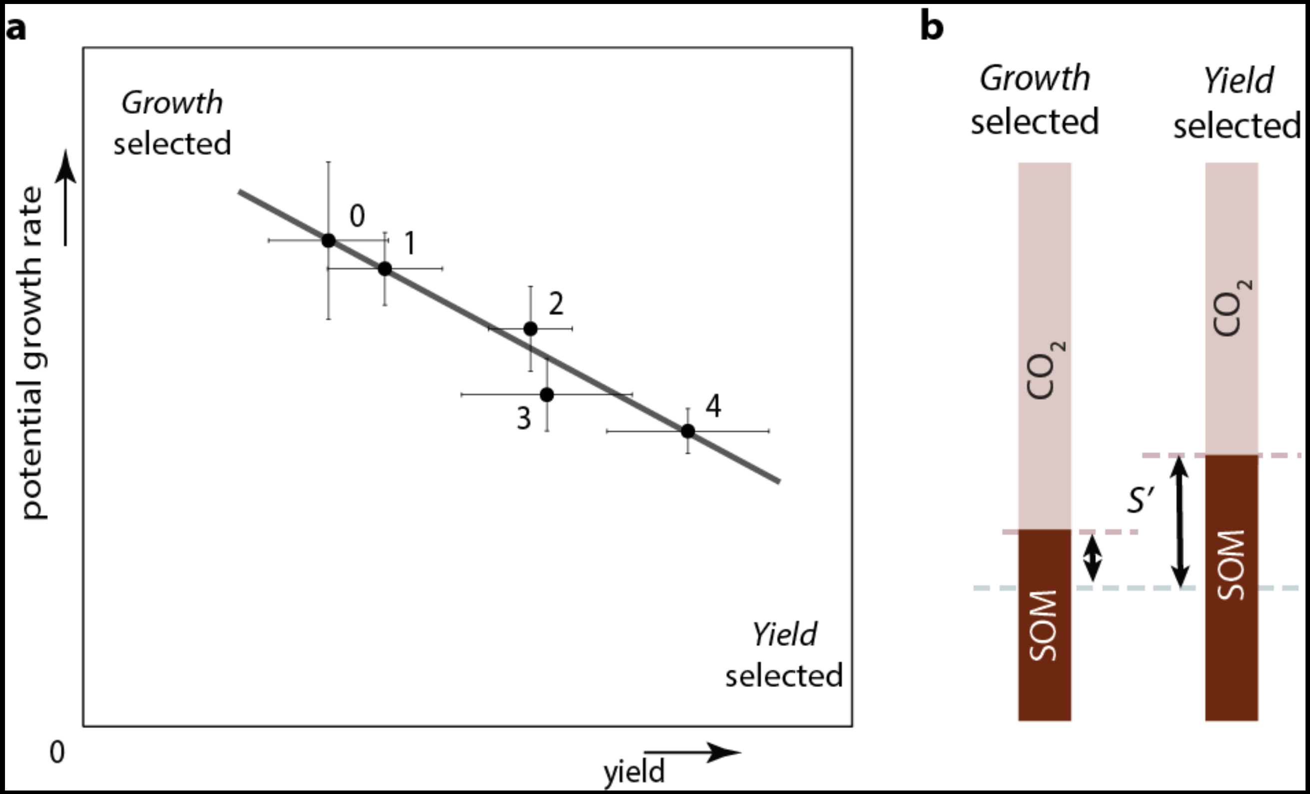
Growth (●) versus yield (◆) strategists



- As dilution increases, competition is decreased
- Maintains higher species diversity than expected
- Ultimately leads to high yield efficiency community

Weidner, Keuskamp *et al. submitted*

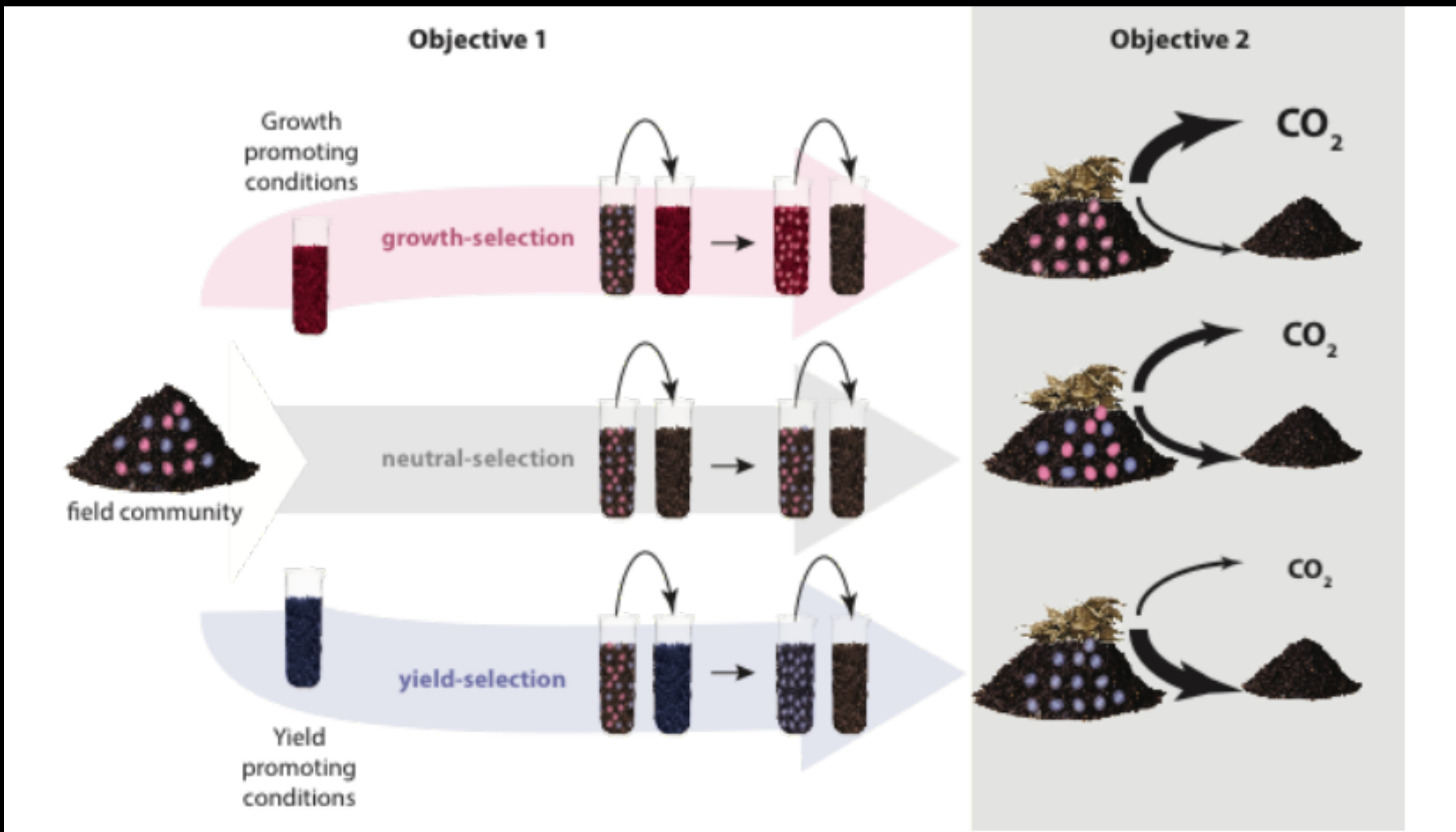
Dilution breeds yield strategies, which impacts C retention



- Tradeoff between growth and yield
- Impact on C retention
- Potential to steer and exploit microbial life history traits

Weidner, Keuskamp *et al. submitted*

Can we steer microbial growth strategies for improved carbon retention?



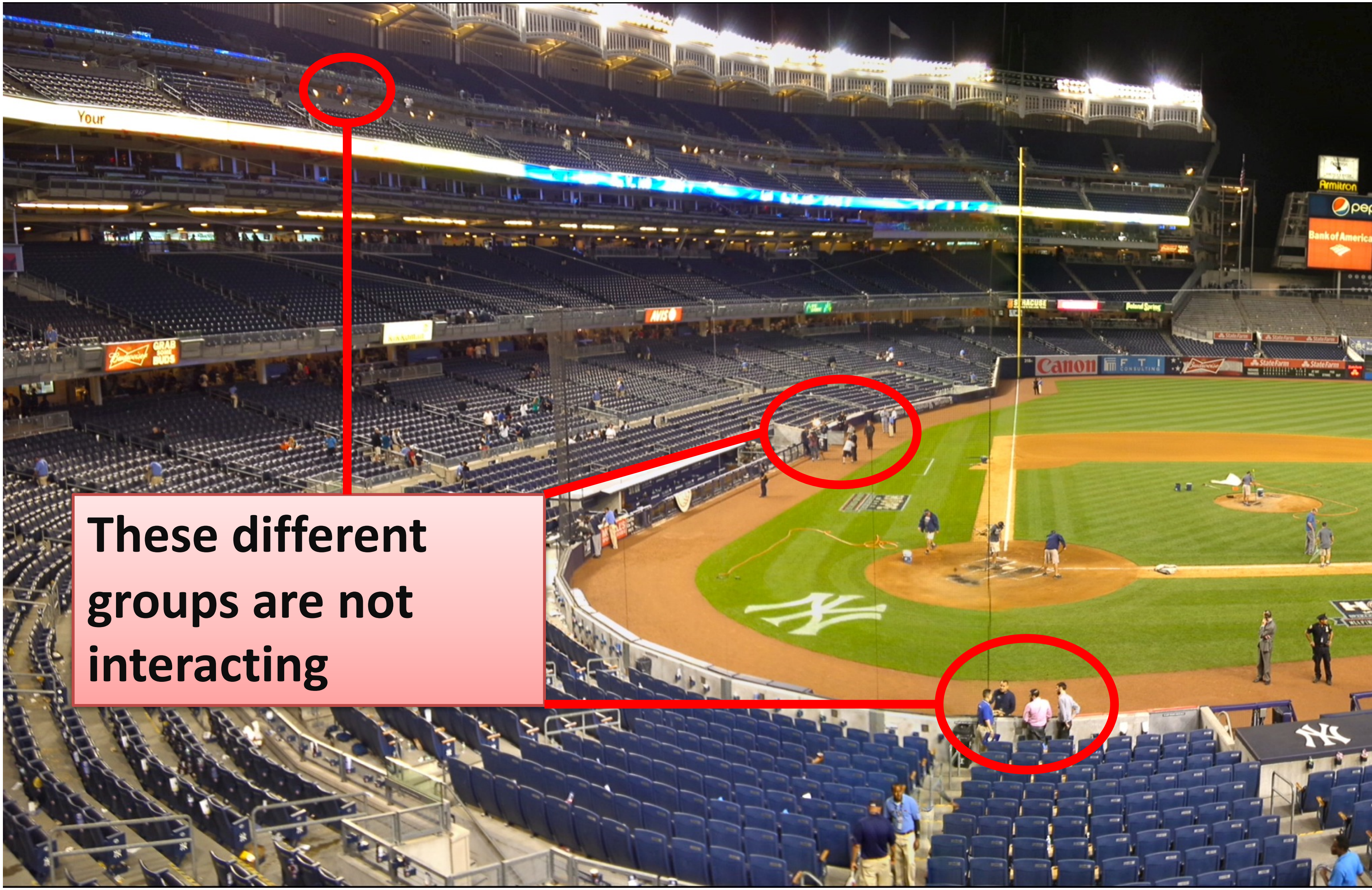
General take-home messages

- Need to rely on plant-microbe interactions in future agronomic approaches
- Plants can steer their functional microbiome
- Need to consider the ecological rules (and scale) that drive microbial community assembly and interactions

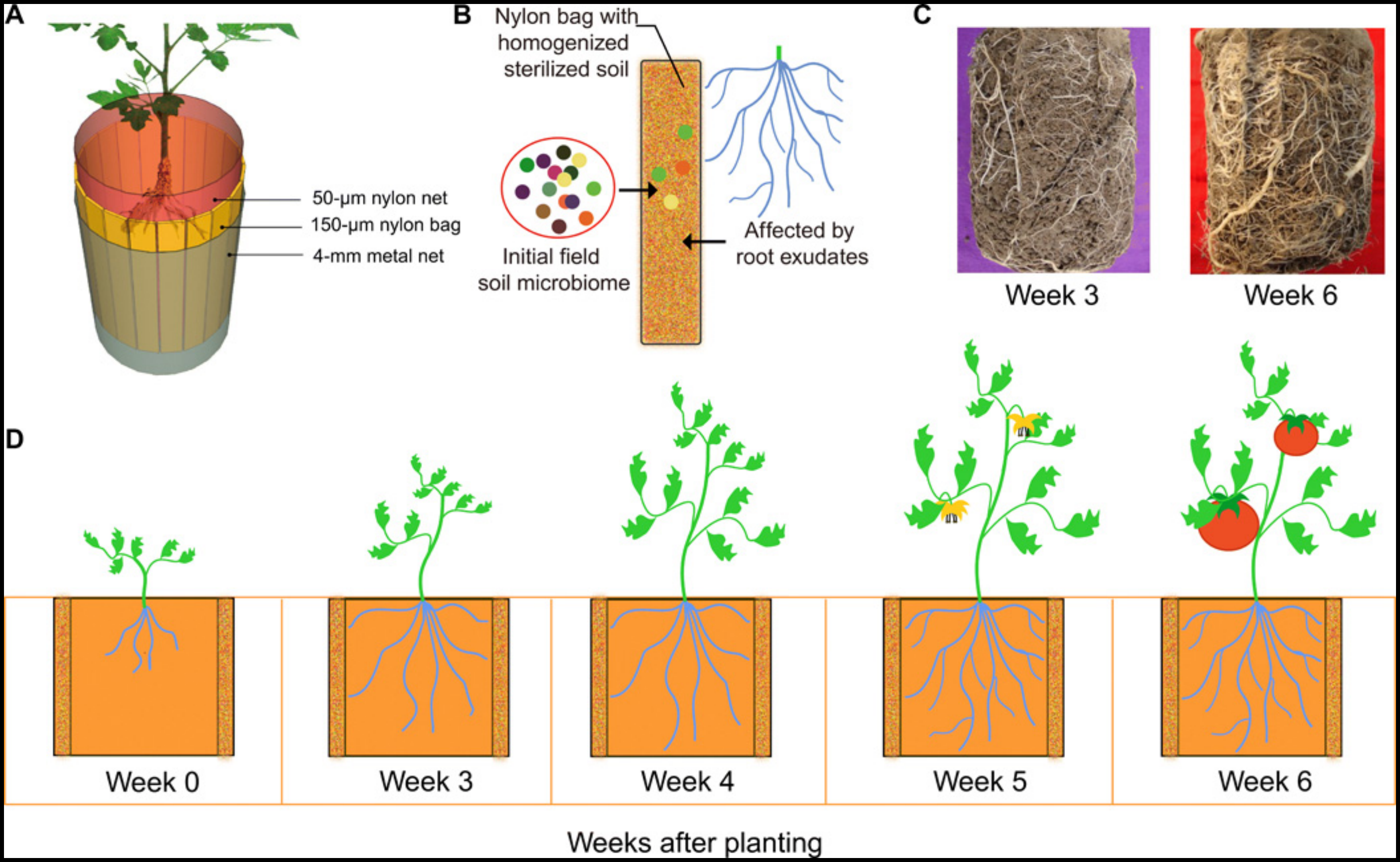
Thank you

Questions???

Most interactions are very local

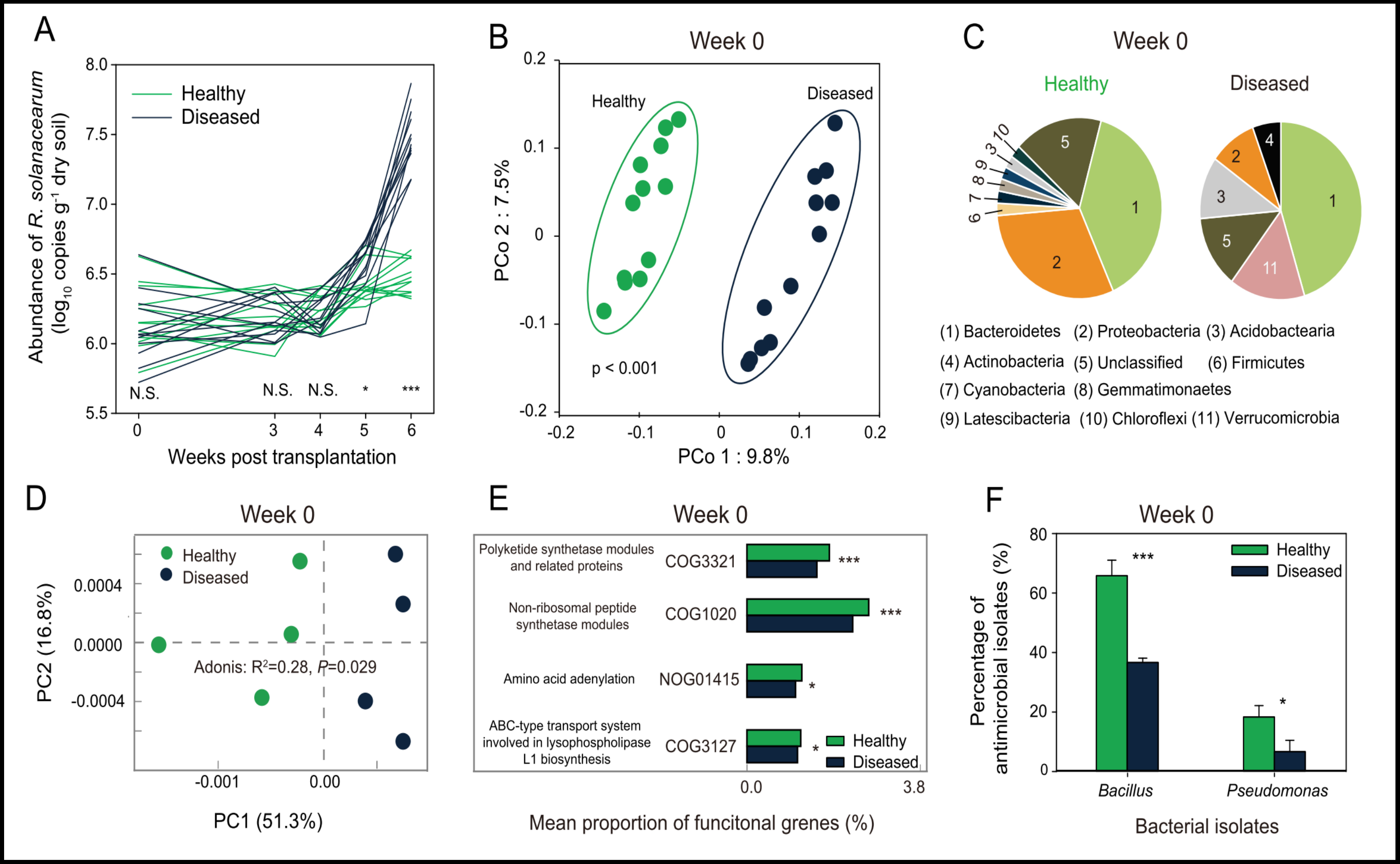


Linking the microbiome with (future) plant health



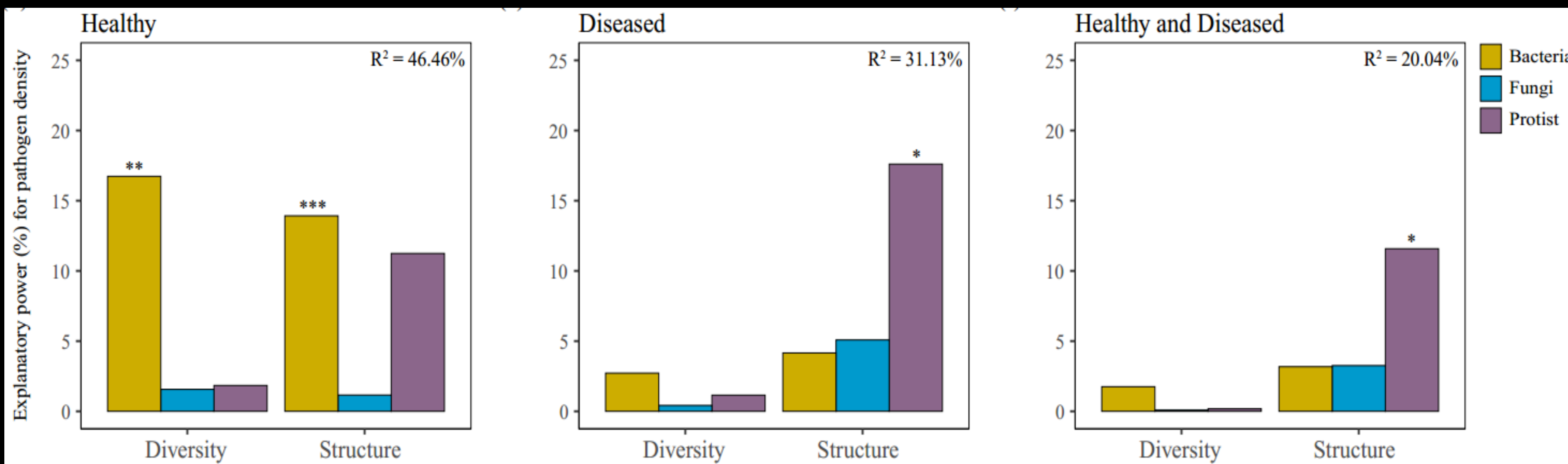
Wei et al Science Advances (2019)

Initial microbiome predetermines future plant health



Wei et al Science Advances (2019)

Protist communities best predict future plant health



Xiong et al *in review*

Two complementary approaches

the dark side…

Micro-scale examination of microbial diversity

into the light…

Experimental manipulation of (artificial) soil parameters

Lower microhabitat connectivity allows for greater bacterial diversity