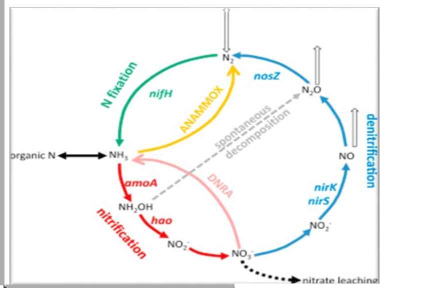

Biological soil health: What we can and cannot learn from common microbial indicators

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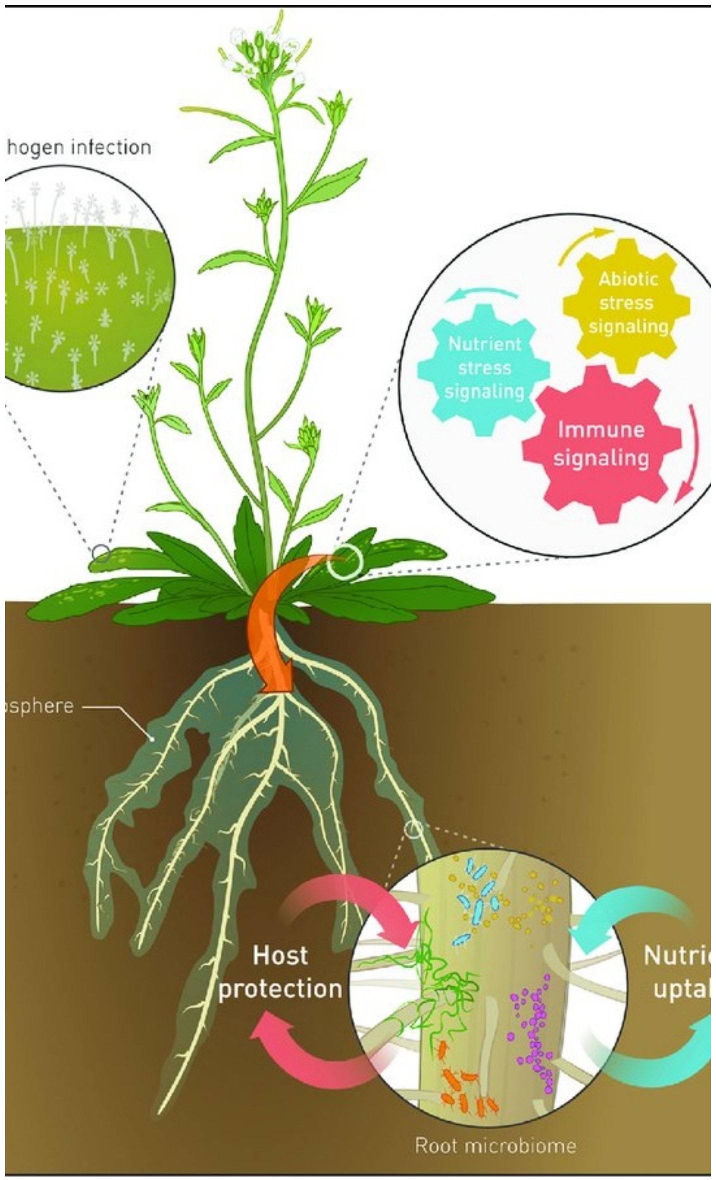
Soil health promotion

- Not a new idea
- Invaluable
- Modern incentives/ interest
- Growing environmental consciousness among consumers, notably Gen Z

Microbial roles in soil health

- Enhance soil water and nutrient holding capacity by influencing aggregate stability
- Drivers of soil nutrient cycling
- Produce and interact with plant hormones
- Reduce pathogen abundances via competitive displacement and/or production of antibiotic and antifungal compounds
- Base of ecological food webs
- Contribute to total soil biodiversity



(Bakker, Pieterse et al. 2018)

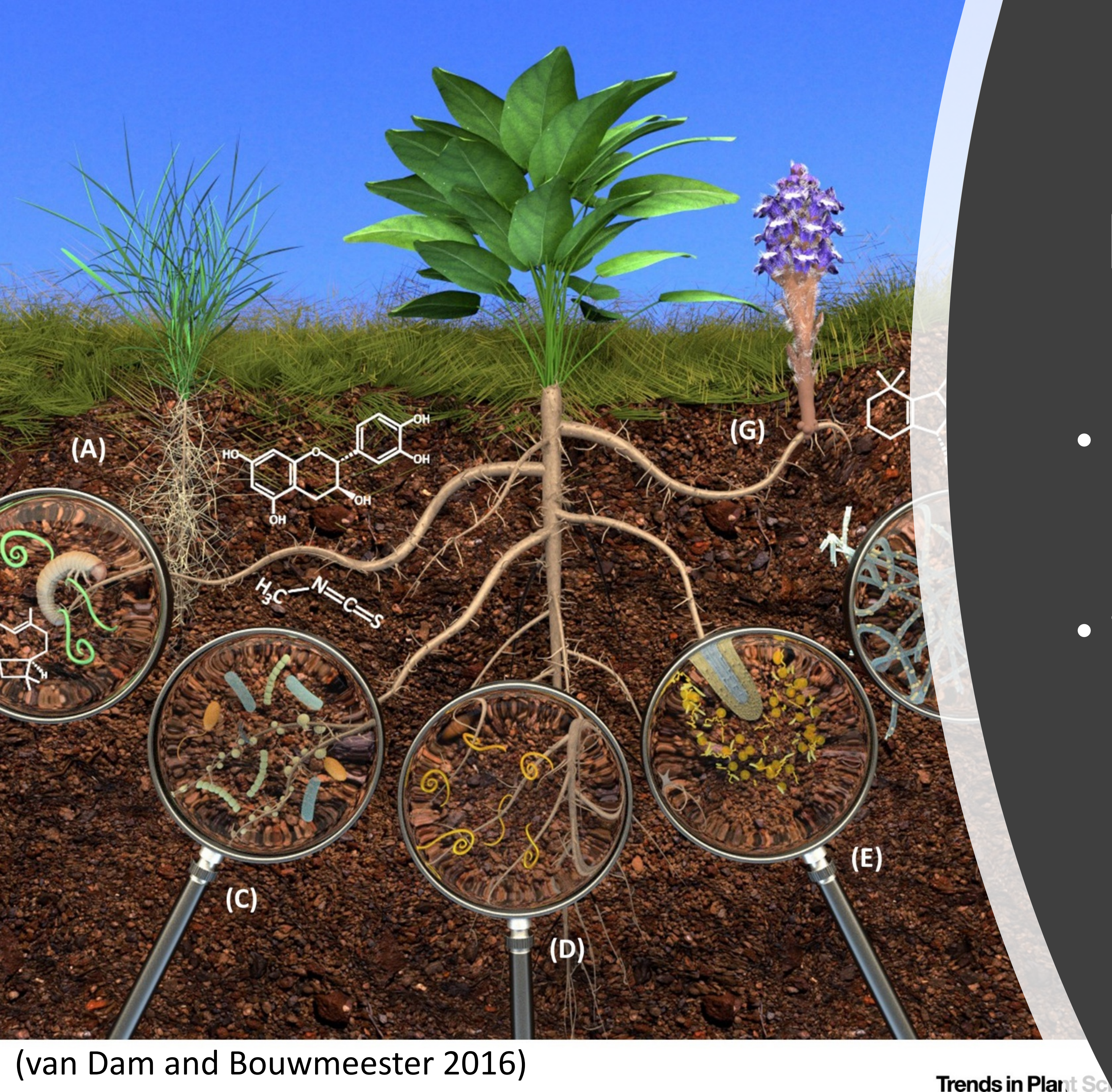

How to best quantify
soil biological health?

There is no single, perfect metric to evaluate a healthy soil biota

Ultimately the insurmountable part of this challenge is the ability to find indicators that are consistent in different climates, cropping systems, seasons, soil types etc.

All biological indicators of soil health have assumptions and limitations

- "Our recommendations rest on a change in mindset away from a universal set of soil health indicators, to a more nuanced recommendation of selecting indicators to meet specific management and/or policy objectives." (Fierer, Wood et al. 2020)
- "Soil health index should reflect soil ability to provide ecosystem services." (Rinot, Levy et al. 2019)
- "Tailoring of methods to local conditions is needed to effectively apply and interpret indicators for different soil resource regions and land uses." (Wander, Cihacek et al. 2019)



(van Dam and Bouwmeester 2016)

Integration of biological health into farm management

- Evaluate and monitor the soil at your site to reveal indicators that are important for your goals
- Take a holistic approach to address biological soil health by adopting practices that are known to mediate symptoms of degraded soils.

Farmers wear many hats (and lab coats too).

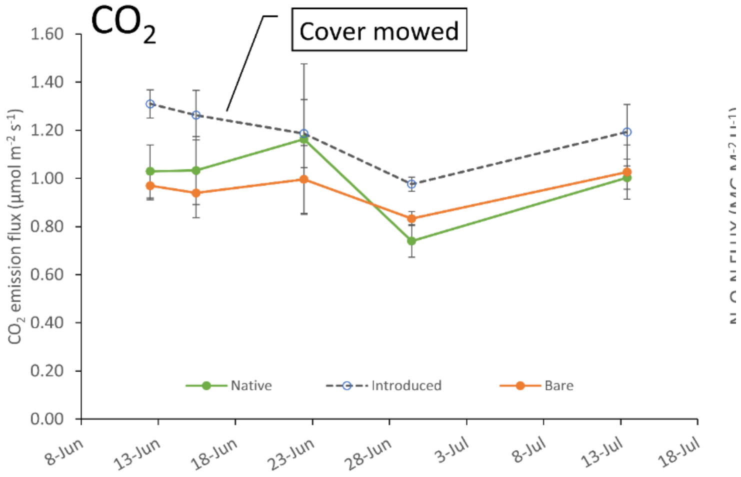
Common biological indicators growers and advisors can use

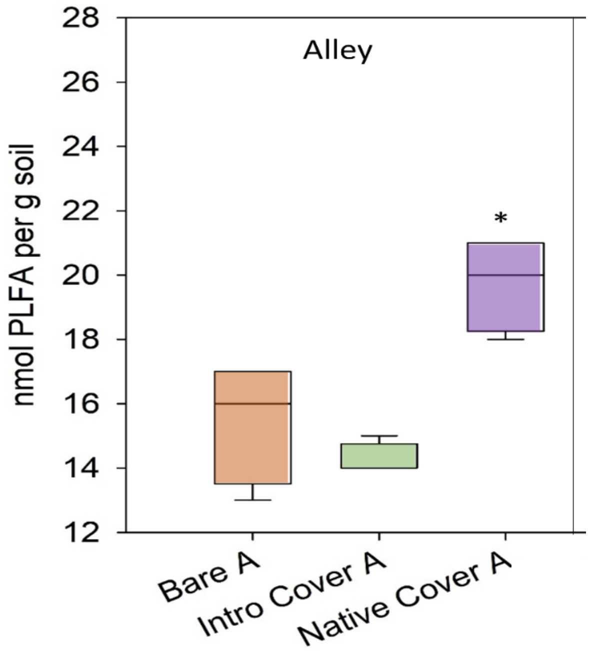
Further reading: Fierer, N., Wood, S. A., & de Mesquita, C. P. B. (2020). How microbes can, and cannot, be used to assess soil health. *Soil Biology and Biochemistry*, 108111.

Carbon mineralization rates

- Evaluates soil respiration (the production of CO_2 per amount of soil per unit time)
- Assumes that greater C mineralization rates is a proxy for greater soil microbial biomass, microbial activity, and/or bioavailable C
- Sensitive to seasonal changes (e.g variations in soil moisture and temperature)
- Pro: Commercial test kits are available
- Con: High CO_2 emissions is not always a good thing

In a table grape vineyard microbial respiration did not increase after cover was mowed, likely owing to dry soil conditions

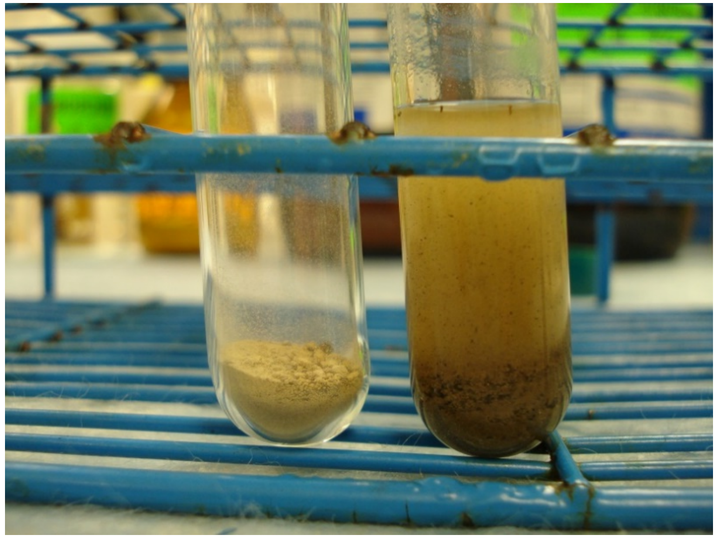


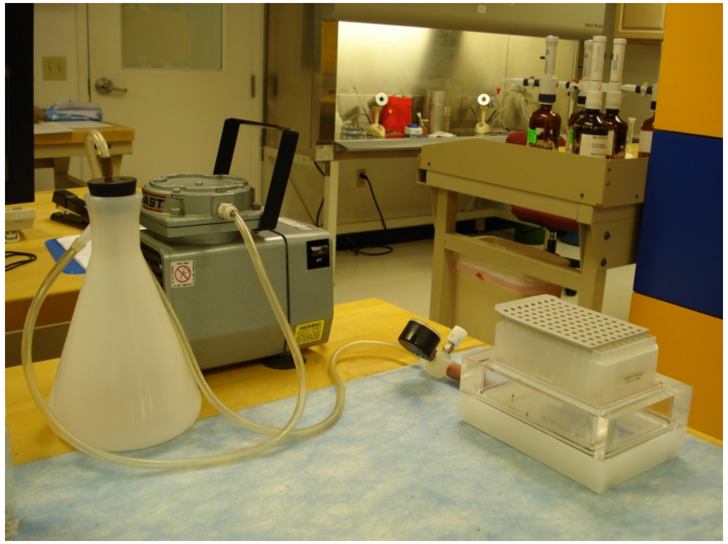


Common biological indicators growers and advisors can use

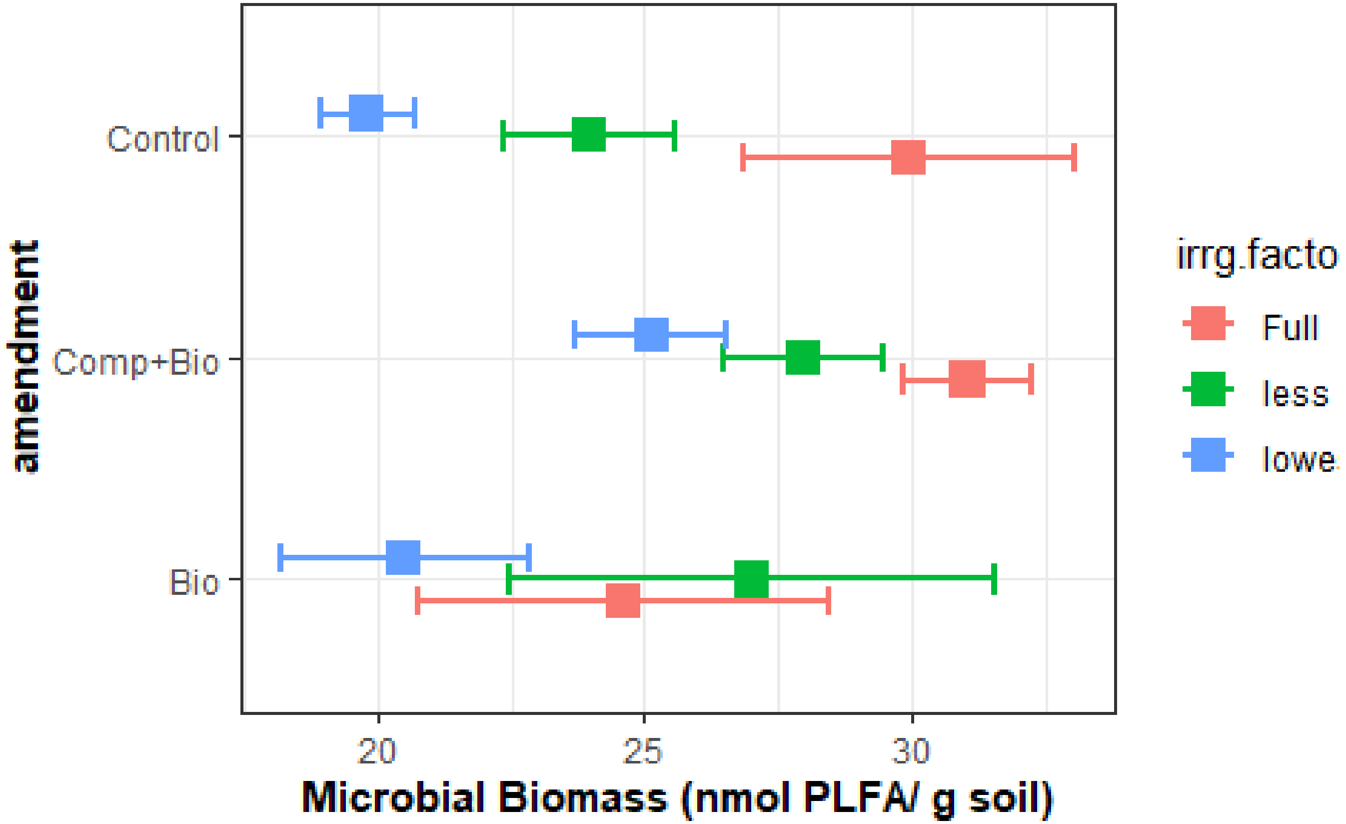
Microbial biomass

- Common tests include analysis of phospholipid fatty acids, fumigation and DOC analysis, and or/ substrate induced respiration
- Assumes microbial biomass is indicative of a healthy biota.
- Sensitive to seasonal variations and sample handling
- Pros: Widely used metric. Informative of heavy degradation
- Con: Does not provide information on the functional capacities or activities of these organisms



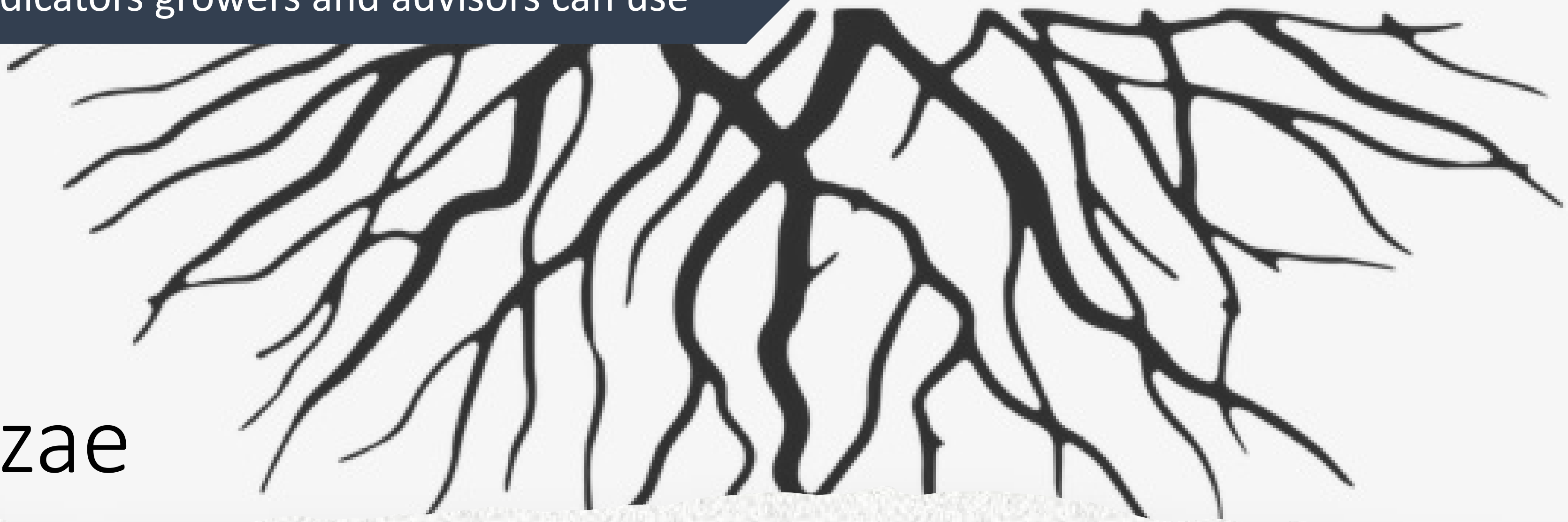


In tomato plots microbial biomass decline with deficit irrigation was less severe in compost amended soil



Fungal to bacterial ratios

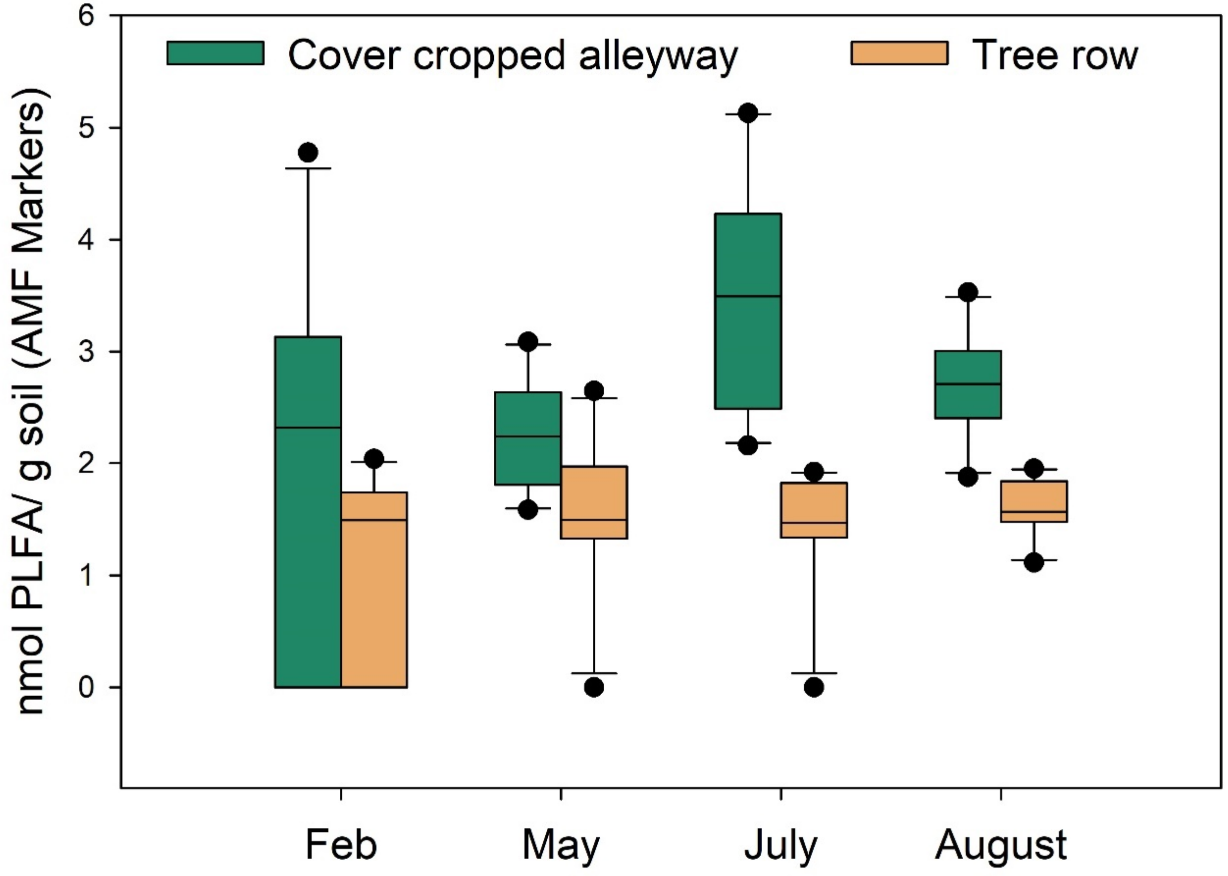
- Relative proportion of fungi to bacteria, acquired through PLFA, qPCR, and/ or microscopy
- Assumption: low fungi:bacteria indicates disturbed, unhealthy soil microbial communities
- Sensitive to sampling location (high within-plot variation), soil depth, and season
- Pro: provides basic information on the composition of the soil microbiota
- Cons: Lacks coverage of the many trophic levels essential for healthy soils. Often fungal PLFA biomarkers are low in agricultural soils so many samples may lack data.



Mycorrhizae

- Quantified with respect to abundance and diversity, typically using stains and microscopy, PLFA biomarkers, and/or molecular techniques.
- Assumes greater abundances and diversity is beneficial
- Sensitive to weekly variations and sample processing
- Pro: focused assessment of a microbial group associated with plant growth promotion
- Con: root colonization and plant growth are not always correlated (correlation is especially low when soil nutrients are not limiting plant growth)

Soil AMF biomass under cover crops increased during season in a pecan orchard

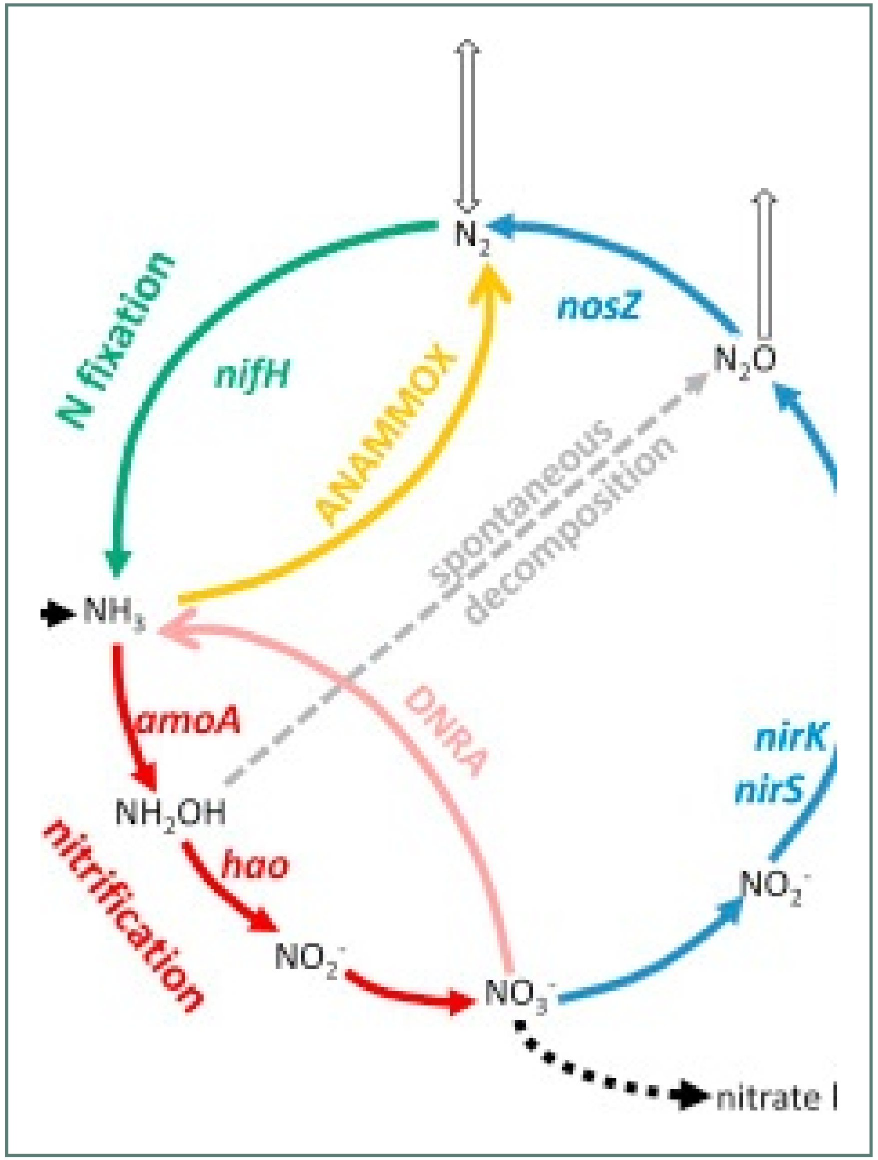


Enzyme activities

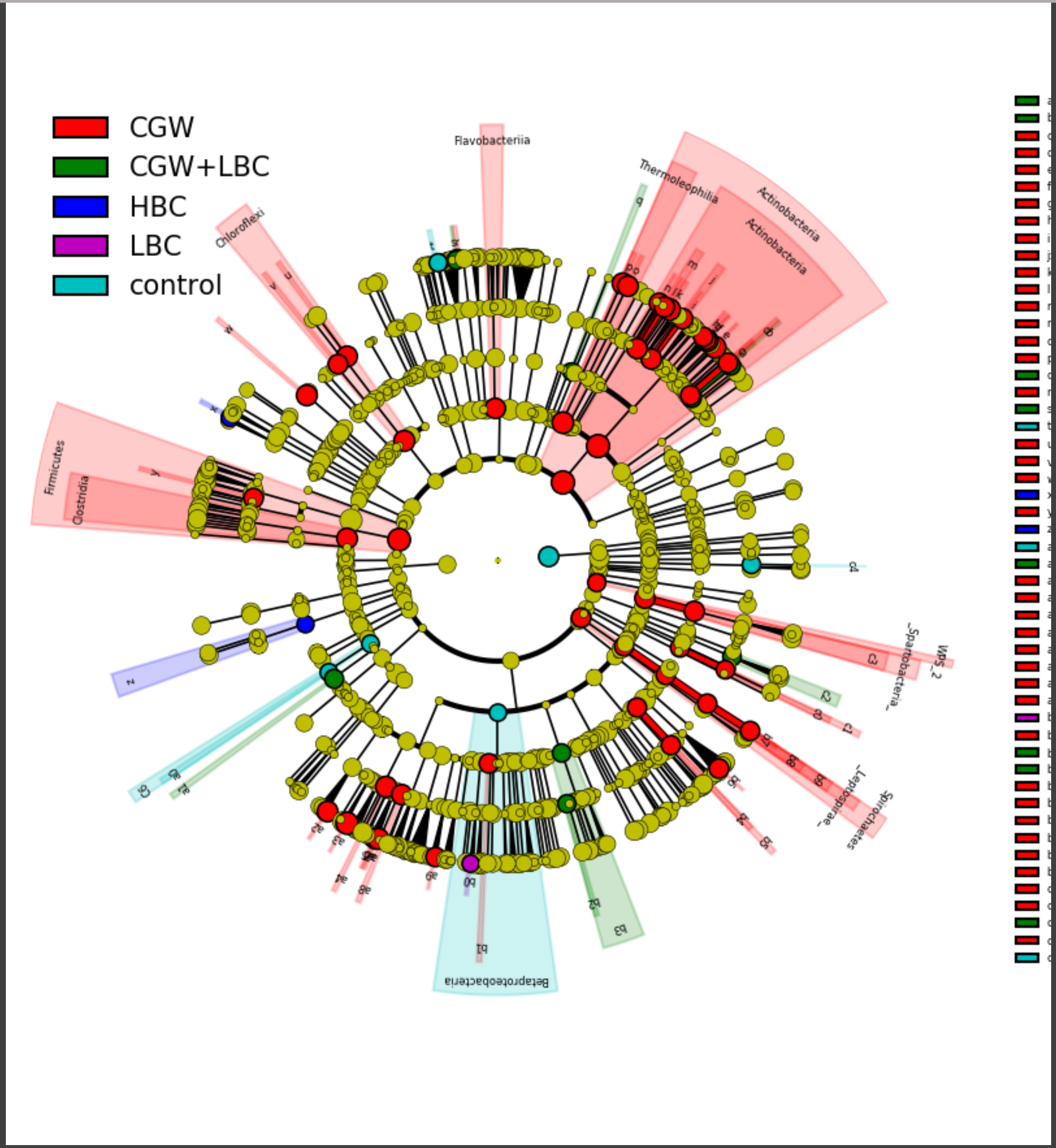
- Measure rate or rate potentials of microbial enzymes in soil. Most common soil enzymes assayed are hydrolase, gulcosidase (C decomposition), amidase, urease, phosphatase, and sulfates (N, P, and S cycling)
- Assumes that greater activities and/or potential to perform activities indicates a functionally robust soil microbiota
- Sensitive to changes in soil conditions (e.g. pH) and most commonly measures are limited to enzymatic potential, not realized activity
- Pros: provides functional information, commonly used, commercial options.
- Con: With the exception of phosphatase, most do not correlate well with nutrient availability

Abundance/ diversity of functional traits

- Typically achieved through molecular techniques, provides information on traits important in soil ecosystem services (e.g. nitrification, denitrification, methane production, plant growth promotion).
- Assumption: functional potential will correlate to changes in beneficial microbial activities
- Pro: provides information on the activities that are important in soil health
- Con: The presence of the gene does not always indicate that the activity occurs



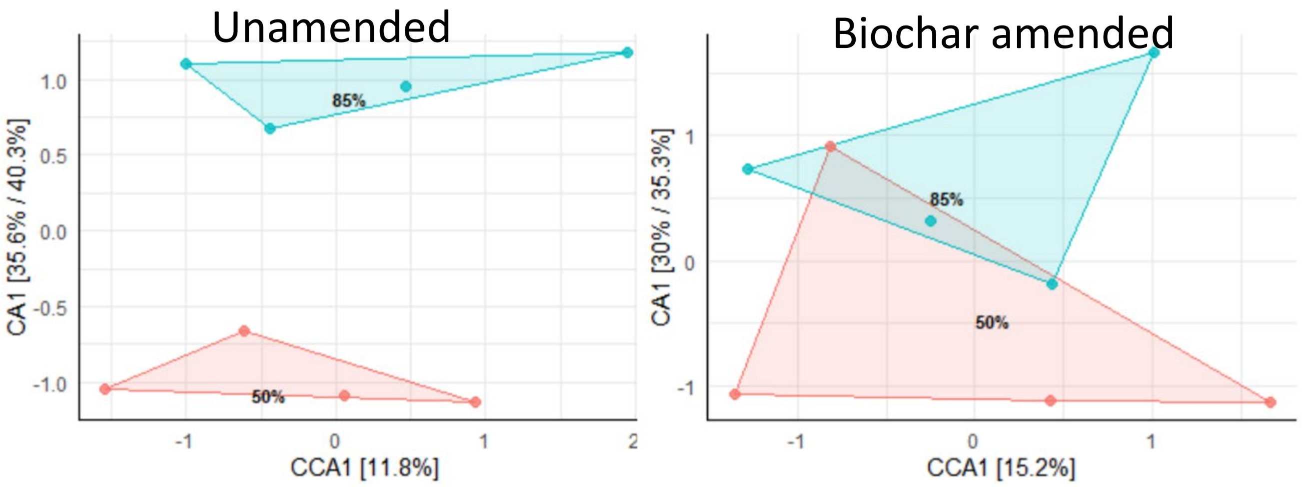
Taxonomic profiles



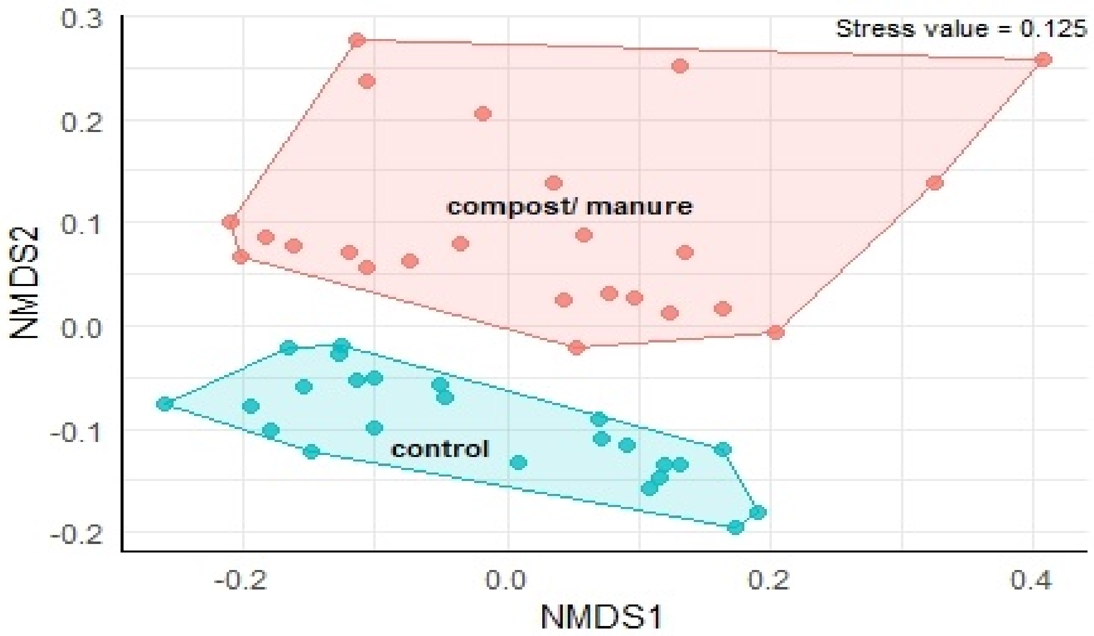
- Use soil DNA or RNA to determine relative abundances of bacterial, archaeal, fungal, or other eukaryotes in soils, commonly via sequencing of molecular markers (16S, ITS, 18S)
- Assumptions: community compositional shifts and diversity indices are indicative of soil health
- Pro: gives a (relatively) comprehensive picture of "who's there". This was not feasible 10 or so years ago.
- Cons: Interpretation is challenging and diversity to function relationships are not always clear.

Bacterial/ archaeal community structure was sensitive to amendments and irrigation levels under turfgrass

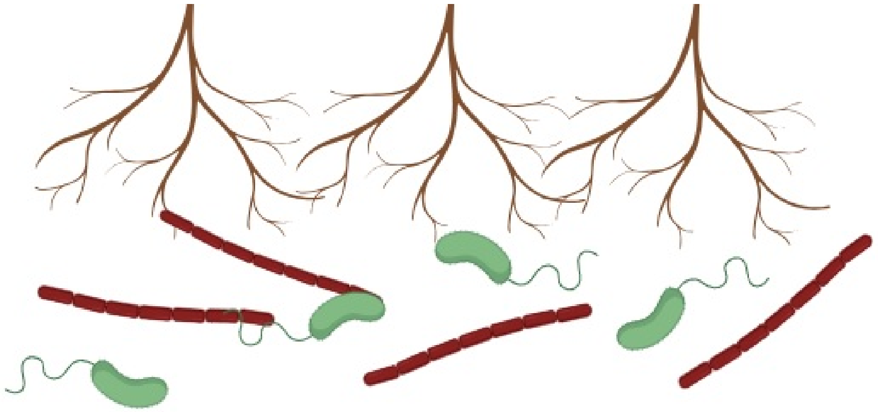
Impacts of deficit irrigation on community structure



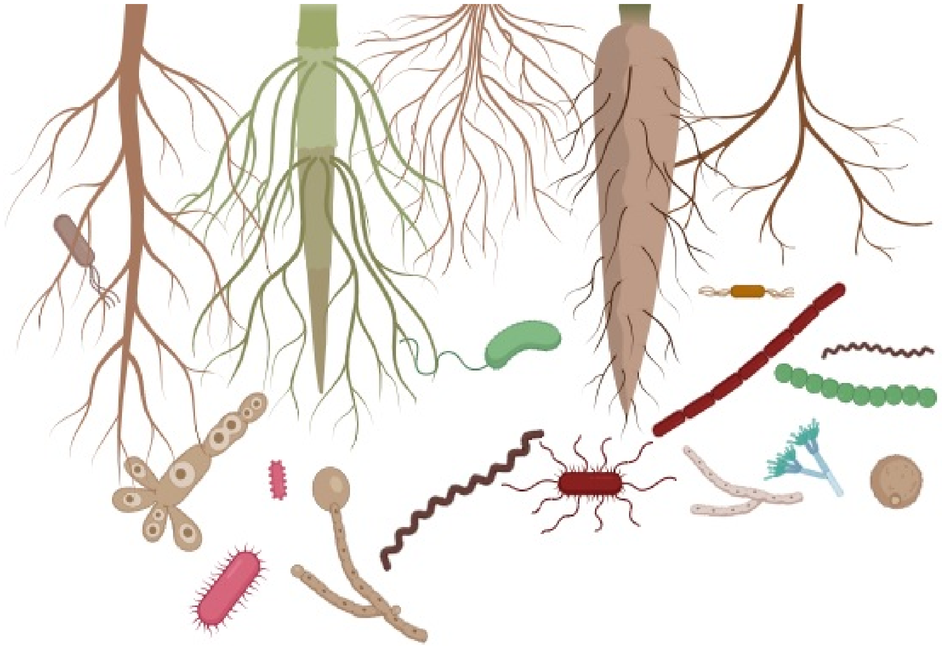
Impacts of organic amendments on community structure



Addressing the symptoms of low performing soil biota



- Low water productivity
- Plant nutrient deficiencies and/or high fertilization demands
- High disease susceptibility



Each of these indicators are not solely attributed to biological processes, but biological processes are important for each of them.

Enhancing water productivity: Case study with cover crops

Table grape vineyard with cool season cover crops

Cover crops mowed/ mulched during peak vine growth

Autumn King grape
Freedom rootstock

Cover crop treatments:
Native mix: dominantly Phacelia
Introduced mix: dominantly Merced Rye
Control: unplanted with heavy weed pressure

April 2020

May 2020

Soil moisture was higher in vine rows adjacent to native cover, even when irrigation timing was reduced

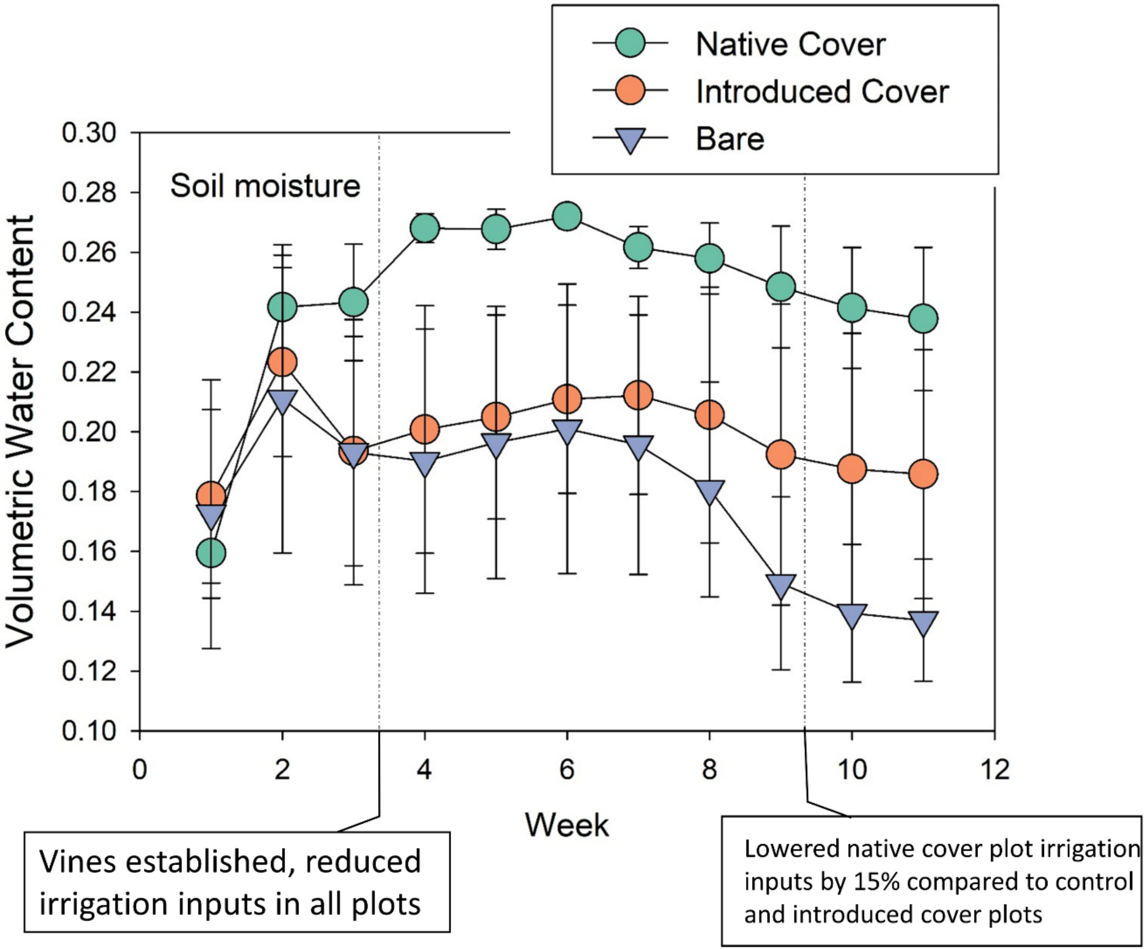
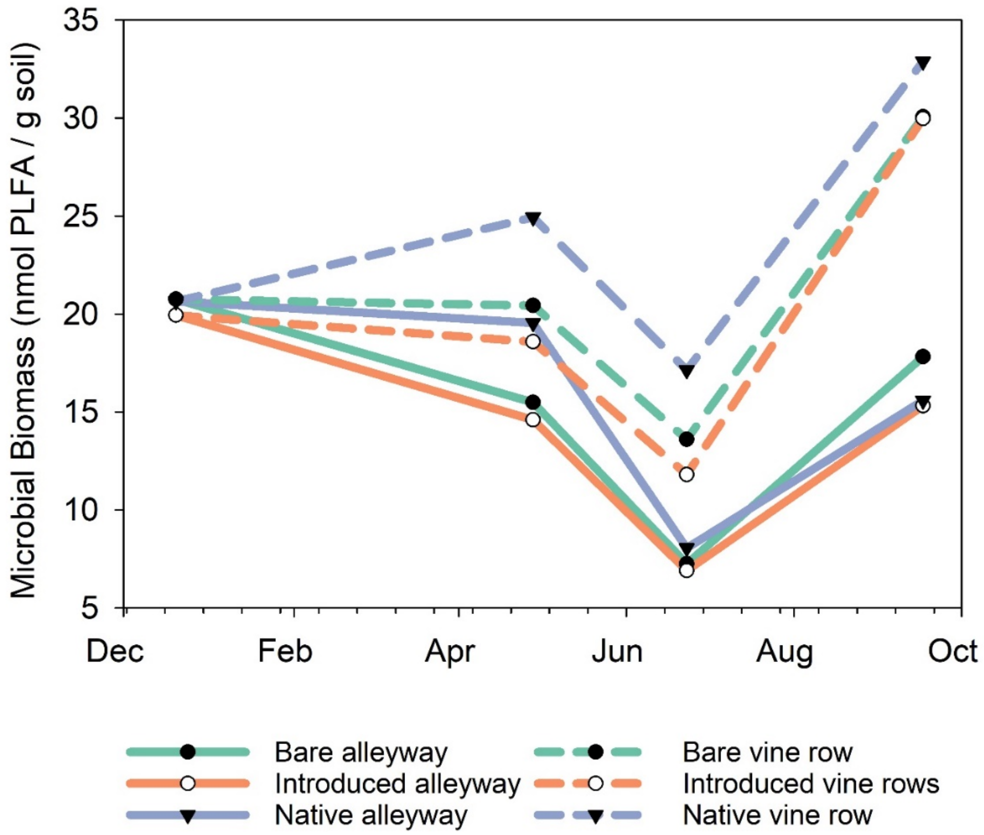


Table grape vineyard with cool season cover crops

Soil microbial biomass increased under vines adjacent to native cover



Preliminary Findings

- Less irrigation water was required to maintain same soil moisture in vine rows adjacent to native cover crop, Phacelia
- Vine rows adjacent to Phacelia also enhanced soil microbial biomass
- Impacts of cover on soil biomass and carbon may have driven shifts water dynamics
- Impacts of cover on weeds will also be assessed
- Likely there are multiple factors contributing to shifts in vineyard water productivity
- Overall, soil microbial indicators are important in determining mechanistic links between cover crops and vineyard water productivity

Key takeaways

- Farm management should be conducted with consideration of the soil biota
- There are no consistent, universal metrics to identify a "healthy soil biota"
- But, there are many metrics that can help understand how management practices impact soil fertility. They can provide a mechanism underpinning why an "unhealthy soil" symptom was exacerbated or alleviated

Acknowledgements

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