Managing Soil Biology to Increase Agricultural Production and Sustainability

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Soil biodiversity: like an iceberg........
... most soil biomass and biodiversity is below the surface
Soil biology provides lots of services to agriculture!!
(and disservices)

- Breakdown wastes, make compost
- Remove pesticides and nutrients in buffer strips
- Develop antibiotic resistance (or not)
- Support plant and animals via mutualism
- Build soil organic matter
- Control and cycle plant nutrients
- Support farmer’s digestion and immunity
- Sequester carbon
- Fix nitrogen
- Biodegrade pesticides in field
- Source/sink of GHG
- Fight/suppress pests (IPM)
- Support farmer's digestion and immunity
- So much is not utilized!
- A lot is taken for granted
- Breakdown wastes, make compost
- Remove pesticides and nutrients in buffer strips

Soil biology provides lots of services to agriculture!!
(and disservices)
Growing concerns about agricultural systems:

- Decreased resistance and resilience (to disease and stresses)
- Contamination of water from improper use of fertilizers and pesticides
- Increasing resistance of pathogens/pests
- Loss of soil (through erosion) and reduction in quality of soil
- Economic vulnerability due to heavy reliance on external inputs (e.g. fossil fuel)
HOW MODERN AGRICULTURE IS NOT FRIENDLY TO SOIL BIOLOGY

STARVATION  We don’t feed soil—residue (=“trash”??) removed or burned, no carbon inputs (cover crops, compost)

PHYSICAL DISTURBANCE  Tillage destroys habitat and breaks apart fungal hyphae

EXPOSURE TO ELEMENTS  Soil left bare—hot, dry, carbon loss

TOXINS  High concentrations of fertilizers and pesticides

LIMITED PLANT DIVERSITY  Monocultures support low soil biodiversity

REMOVE OPPORTUNITIES  Fertilizer shuts out symbiotic organisms.
Most agricultural practices are focused on plant (even when involving soil)

• Often target single issues rather than systems oriented

• Address symptoms not underlying cause

• Usually short term perspective (that season)

• May come from consultants who spend little time on farm
How can we benefit more from soil biodiversity?

1. Manipulate conditions to influence native microorganisms (“prebiotics”) and/or

2. Add organisms (often non-native) as inoculants (“probiotics”)

Just like in human health applications.
MANAGEMENT to promote native soil microbial communities
Soil Biology does not exist in a vacuum. Soil health, agroecology

Carbon is the key driver of the soil nutrient-microbial recycling system. Carbon is also the key driver for soil moisture holding capacity.

Soil Health Principles:
- Plant Diversity
- Living Roots throughout the year
- Cover the Soil
- Less Disturbance
- Grazing where applicable

The Soil Food Web (SFW) refers to the collection of microorganisms and micro-arthropods in the soil that interact directly or indirectly with plants, decompose organic matter, or prey on the organisms that interact with plants.

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/nm/technical/?cid=nrcs144p2_068965

Ref.: Cornell Soil Health Assessment Training Manual

rudy.garcia.2014
Soil biology is intimately connected to physical environment and chemical processes
Fertile Soil Doesn't Fall from the Sky: Contribution of Bacterial Remnants to Soil Fertility Has Been Underestimated Until Now

Dec. 14, 2012 — Remains of dead bacteria have far greater meaning for soils than previously assumed. Around 40 per cent of the microbial biomass is converted to organic soil components,

Soil organic matter is formed out of dead microbes

Plant C → microbe C → organic matter C

Miltner et al.. SOM genesis: microbial biomass as a significant source. Biogeochemistry, 2011
Soil organic matter is correlated to living soil microbial biomass.

<table>
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<th></th>
<th>Organic</th>
<th>Conventional</th>
<th>No Input</th>
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<td>Soil organic carbon</td>
<td>1.4%</td>
<td>1.0%</td>
<td>0.78%</td>
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<tr>
<td>tomato</td>
<td></td>
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<td>Wheat no fertilizer</td>
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Relationship of microbial biomass nitrogen and plant available nitrogen

Protozoa help release organic N as NH4+
SOIL STRUCTURE
Built by biota (“architects”) out of carbon and minerals

Macroaggregate
- Roots
- Hyphae

Microaggregate
- Root hairs
- Hyphae
- Polysaccharides

Submicroaggregate
- Mineral grains encrusted with plant and microbial debris
- Plant debris coated with clay

Primary particles of silt, clay, and humus
- Clay and clay-humus domains

larger <<---------------------------------------------------------------smaller
Implications of structure for water movement and gas exchange

a. Well-structured soil
- Air, water and nutrients stored in pores
- Water remains near surface
- Water and nutrients move very slowly down profile; air may be excluded

b. Poorly structured soil
- Very small pores
Interview with Scott Park—organic vegetable and rice farmer (750 hectares) in California for 25 years Converted from conventional system (mineral fertilizer, pesticides).
Scott’s Philosophy

FEED THEM

GIVE THEM SHELTER

KEEP THEM COVERED

DON’T DISTURB THEM TOO MUCH

DON’T TRY TO DO TOO MUCH

GET OUT OF THEIR WAY (especially later)
Management practices for managing microbes in soil

- Manipulate what they eat: C/N ratio of organics, degradability, physical availability, electron acceptors (e.g. oxygen), other nutrients, specific enzyme co-factors (?)

- Manipulate their environment: water and oxygen content, pH, “architecture”: stratified vs mixed layers in soil

- Inhibit/select for specific microbial groups? Nitrification inhibitors? Selection through substrates, signaling compounds?

- Promote symbiotic relationships with plants that short-circuit some of the soil processes providing N

Coupled with new research directions

- High throughput sequencing (e.g. metagenomics) to measure responses and identify native organisms involved in desired outcomes
  - Who is there?
  - What do they do?
  - What do they need?
the other approach.....

INOCULATION w/non-native organisms

Rising interest in isolating or engineering specific microbes and using as soil inoculants

Major agtech companies jumping into this area
WHY DOES INOCULATION WITH MICROBES OFTEN FAIL?

- Incomplete understanding of abiotic requirements
- Incomplete understanding of biotic requirements – need right partner? Other microbes?
- Environmental conditions not right (no rain, no food, etc.)
- Application method doesn’t get them where they are needed
- Intense predation or competition by residents (e.g., protozoa)
- Inoculum usually commercially produced under optimum conditions for growth—too weak or pampered to survive?
More targeted strategies to increase success of inoculation—focus on plant and microbes, lots of “omics”

Bakker et al., 2012
Soil health/quality is coming back after having lain dormant for 15 to 20 years. NRCS launched the initiative in 2012. Many modules, management systems, indices, kits available. Cornell, NRCS,
NEED TO CONNECT PUBLIC WITH AGRICULTURE’S BELOW GROUND “YIELDS”

State and county fairs give prize for biggest pumpkin…..

How about prize for soil with greatest biomass or biodiversity?