THE MICROORGANISM SUPER HIGHWAY: MANAGING SOIL BIOLOGY

John P. Brooks USDA-ARS
Soil Biology – The Master of the Universe

- Soil biology controls all aspects of soil health...
  - All aspects of plant health...
  - All aspects of animal health...
  - All aspects of human health...

Sources: Texas A&M, Plantdesigns.com, earthobservatory.nasa.gov
## Components of Soil

<table>
<thead>
<tr>
<th>Mineral Fraction (95-99% by weight)</th>
<th>Organic Fraction (1-5% by weight)</th>
<th>Biological Fraction (≈ 0.05% by volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Organic debris</td>
<td>Virus</td>
</tr>
<tr>
<td>Silt</td>
<td>Colloidal organic matter</td>
<td>Bacteria</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td>Fungi</td>
</tr>
</tbody>
</table>

- **Typical areas of soil biological activity**
  - **Rhizosphere** – Hiltner (1904) defined as portion of soil where microorganism-mediated processes are under the influence of the root system
  - **Vadose** – Limited soil biological activity, but more work currently focused on this area
Components of Soil (Rhizosphere)

- Water
- Sand
- Bacteria
- Root
- Clay
- Organic Matter
- Bacteria
- Sand
Soil Microbial Population – What do they do?

- Positive interactions
  - Biocontrol of pathogens
    - Antibiotic induced
    - Creation of niches – outcompeting
  - Phytohormones (PGPR)
    - Promotes plant growth – auxin and cytokinin
  - Micronutrient availability
    - Increase solubility
  - Stress tolerance
    - Salt and drought tolerance

- VERY FEW NEGATIVES
  - Plant pathogens
  - Biogeochemical cycles gone wild
Overall Factors & Agronomic Practices that Affect Soil Biology

- **Environmental Factors**
  - Soil quality: type and structure
  - Geography
  - Climate (E.g. Moisture, temperature…)
  - Animals/Grazers
  - Anthropogenic activities

- **Agronomic Factors**
  - Crop/Plant health
  - Type of fertilizer
  - Treatment/Pesticides
  - Tillage

IPCC; 2012
Dominant Factors

- **Soil**
  - pH

- **Climate**
  - Temperature swings
  - Extremes in moisture

- **Plant or crop**
  - Includes cash crop AND cover crop systems
Soil attributes drive soil microbial population niches

- Sand vs clay, metals, physicochemical attributes
- pH – drives gradient based microbial populations (da C Jesus et al., 2009)
  - Primary and secondary forests tend to be similar in pH and microbial population
  - Pasture and crop soils – more neutral pH tend to cluster

Notice clustering of “like” pH soils
Climate

- Soil microbial population - Natural fluctuations as a function of temperature and moisture
  - E.g. Meier et al., 2008
    - Minimal changes to the overall populations
    - Changes to specific sub-populations
  - Brooks et al., 2012 and unpublished work
    - MS – 2006 through 2007 experienced drought-like conditions
    - Moisture can cause bacteria to fluctuate by 10,000 fold
Climate

- Temperature – may become the new dominant attribute
  Garcia-Pichel et al., 2013 – bacteria are known to operate under strict (bend but don’t break) bounds
  - Entire shifts in population dominant species based on temperature changes
    - Specifically Cyanobacteria – biocrusts dominant phylum
    - Genera such as Microcoleus spp.
    - Pioneering primary producer – imperative to arid lands

Temperature Drives the Continental-Scale Distribution of Key Microbes in Topsoil Communities

![Graph showing the relationship between temperature and fraction of cyanobacteria.](image)
Plants exhibit a strong influence on surrounding soil:

- Release root exudates
  - Stimulate chemotaxis, adherence, and colonization
  - Antimicrobial products
- Provide nutrients for soil microbes

Genotype and historical lineage can influence the soil biology (Germida et al., 2001)

Shifting crops and intercropping appears to increase the microbial population

**Table 4** Interaction effect of cropping system and fertility on dehydrogenase activity of soil (microgram TPF per g soil per day) at harvest of Bt cotton (mean data of 2 year)

<table>
<thead>
<tr>
<th>N dose (kg ha(^{-1})) and source (% urea-N-% FYM-N)</th>
<th>Cropping system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sole cotton</td>
</tr>
<tr>
<td>Control (0-0)</td>
<td>86.4</td>
</tr>
<tr>
<td>150 (100-0)</td>
<td>103.6</td>
</tr>
<tr>
<td>150 (75-25)</td>
<td>150.6</td>
</tr>
<tr>
<td>150 (50-50)</td>
<td>209.4</td>
</tr>
<tr>
<td>±SEM</td>
<td>4.58</td>
</tr>
<tr>
<td>CD (P=0.05)</td>
<td>13.73</td>
</tr>
</tbody>
</table>

CDJ critical difference (Singh et al., 2013)
Common Properties of Cover Crops

- **Cover crop**
  - Any crop grown to provide soil cover
  - Some are incorporated later, some are used as mulch, some are incorporated green (Summer green manure crop vs. Winter cover crop)
    - Primarily reduce soil erosion
    - Increases soil organic matter, water infiltration, and microbial populations
    - Increase water holding capacity (1.7 to 4.2 inches of soil water)
    - Fix nitrogen – legumes and rhizobacteria
    - Reduce N leaching
    - Suppress weeds and reduce insect pests
Effect on Soil Biology - Increasing Soil C

- Buyer et al., 2010
  - Cover crop – increased available C
    - Microbial biomass increased by vetch and rye cover

- Select for some sub-population
  - Possibly due to exudate release or degradation (Wang et al., 2007)
Effect on Soil Biology – Management

- Management Approach
  - Mowed/Not Tilled
    - Steenwerth et al., 2008; Buyer et al., 2008
  - Rye and Trios Cover increase microbial population
- Some microbial sub population selection
  - Most likely soil C (Buyer et al., 2010)
Effect on Soil Biology – Management

- **Incorporation**
  - Schmidt et al., 2003
    - Organic matter input resulted in fewer worms from cover crop enriched worms
    - Conventional tillage resulted in fewer worms
    - Direct drilled (aka minimal disturbance) resulted in more worms
  - Seigies et al., 2006
    - Selection of cover crop influences soil microbiology, fungal vs. bacterial
    - Cover crop rotations – led to performance and disease suppression = methyl bromide

![Graphs showing effect of cover crops on earthworm abundance and biomass](image)
Effect of Soil Biology – Disease Suppression

- Suppression of disease pathogens
  - Oger et al., (2000)
    - Use of colonizing bacteria to prevent disease – opine producers
    - Difficult in practice – if not a natural symbiont
    - Suggested use of opine producing crops
      - Recruit opine harvesting organisms, which colonize roots
      - Prevent pathogen colonization
      - Appears sustainable for a period of time

![Dynamics of opine-utilizing bacterial populations in bare soil. The variations of the density of opine utilizers were recorded in bare soil after the removal (t₀) of normal plants (circle) or transgenic plants producing opines (diamond) (t₁–t₅).]

- Opine consumers increased as a result of transgenic plants
- Opine consumers remained high following removal of plant
Effect on Soil Biology – N increases & Reduced N loss

- Legume as cover – increase N
- Biculture with a legume (E.g. clover, soybean, hairy vetch, etc) and non legume as cover crop (Kuo et al., 2001)
  - Increase fixed N in soil
    - Dominated by rhizobacteria
  - Decrease fertilizer inputs
    - Sidedressing N was lowest in vetch/ryegrass and rye
  - Increased N leachate
    - Biculture – negated this consequence
Effect on Soil Biology – Soil Glue

- Reduce soil erosion
  - Production of glomalin
    - Arbuscular mycorrhizal fungi produce glomalin
      - Beneficial relationship between plant and fungi
      - Hyphae will scavenge nutrients using glomalin
    - Unnoticed benefit – “gluing” of soil particles
    - 60-70% plants are mycorrhizal
    - Plant species may determine glomalin and type production rates (Rillig et al., 2002)
Conclusions

- Benefits – Diverse microbial population is always a good thing (well maybe)
  - Disease suppression
  - Strong biogeochemical cycling
    - Reduced fertilizer inputs
  - Well bound soil particles
    - Nutrient recruiting

- Most specific effects cannot be generalized
  - Effects are cover crop/system specific
Contact Information

- John P. Brooks
  - USDA-ARS – Mississippi State University
  - 810 HWY 12 E., Mississippi State, MS 39762
  - Email: john.brooks@ars.usda.gov
  - Phone: 662-320-7411