THE BIOLOGY OF SOIL HEALTH FOR COMPOSTERS

Growing Our Markets and Our Opportunities
Our Purpose Today

- Introduction - what has all of this stuff about soil health got to do with the composting industry? (a whole lot, it turns out......)

- The Biology of:
  - Soil Structure
  - Fertility
  - Soil Carbon

- Creating healthy soil ecosystems (concepts, principles, practices)

- Compost Opportunities: Marketing the Multi-Purpose Soil Health BMP
The Soil is Alive!

What does this really mean?

One handful of garden soil: more living organisms than there are people on the planet!

Soils = Living Ecosystems
Why is Soil Life So Important?

Web of soil organisms - predators and prey - are responsible for about 90% of the soil functions that make above-ground life possible.

Surface of Mars -- Photo
Credit: NASA and the NSSDCA
The Soil Food Web is a Community

Like our own communities, it organizes itself to optimize conditions for its members.

To do this, it uses the energy that comes from the above-ground ecosystem.

For example, the community organizes a soil structure similar to our community infrastructure.
The Biology of Soil Structure

...and the key to water management
Soil Structure

Physical components of soil:
- Sand -- 0.5 to 2 mm
- Silt - between .002 and 0.5 mm
- Clay -- less than .002 mm
- Organic matter -- varies

Bathtub analogy:
Basketballs, marbles, small beads and....smaller!
The Key Factors and Players in Soil Aggregation Processes

- Electrical charges, chemical attractions: clay particles, organic molecules
- Biological glues: earthworms, bacteria and fungi
- Threads: roots and fungi
Bacteria: The Glue Guys

Microscopic: fraction of a micron diameter; a few microns in length (micron = one millionth of a meter)

One teaspoon of healthy soil contains roughly how many bacteria?

Between 100 million and a billion

Photo credit: Soil and Water Conservation Society. SWCS. 2000. Soil Biology Primer
Bacteria - The Harmful, the Helpful and the Ancient Partners

3 main functional groups (defined by where they get their food energy):

- Pathogens
- Decomposers
- Mutualists

A productive soil has the bacterial biomass equivalent to 2 cows per acre

Source: Soil and Water Conservation Society
Bacteria in Action

Video Credit: Tim Wilson of Microbe Organics
Fungi: The Nice, the Nasty and the Carbon Traders

3 types of soil fungi:

Decomposers (saprophytic fungi)

Plant parasites (pathogenic fungi)

Mutualists (mycorrhizal fungi)
Fungi - Some Key Facts

Important decomposers, breaking down tough materials, such as lignin

Grow as long threads, known as “hyphae”, which are just a few microns in width

Mycelia are groups of hyphae massed together (these are often visible)
Fungal Hyphae under the Microscope

Video Credit: Tim Wilson of Microbe Organics
Bacteria & Fungi: The Soil’s Structural Engineers

Soil Aggregate Formation - step by step

1 - Chemical and electrical forces attract particles to each other

2 - Bacteria, earthworms, fungi secrete organic glues, bind particles of clay, silt, sand into tiny aggregates

3 - Fungal hyphae (filaments) and roots/root hairs bind these into larger soil aggregates
Attributes of Stable Soil Aggregates

1. These large aggregates are of different sizes and shapes and thus create pore spaces.

2. The glues and hyphae are water-resistant and thus stable under most conditions.

3. Well-aggregated soils are ideal environment for both microbes and plant roots.
Network of fungal hyphae stabilizing an aggregate

Eickhorst, Thilo & Tippkoetter, Rolf. Micropedology - The hidden world of soils. University of Bremen, Germany. [http://www.microped.uni-bremen.de](http://www.microped.uni-bremen.de)
Good soil structure - crumbly, well aggregated

Field: Adam Ireland, Teeswater (same field, cover cropped vs not). Photo: Ontario Soil Network (Mel Luymes)
Ray Archuleta and the Infiltration Test

- https://www.youtube.com/watch?v=cx_hmse9Se8
The Biology of Soil Fertility

...and the key to input efficiencies
Natural Fertility

What used to be the full story:

- Weathering & decomposition
- Mass flow of nutrients
- Diffusion

What were we missing in this story?

The extensive and vital role of microbes in the following:

- making **nutrients** plant-available in the right place, at the right time
- **Trading nutrients for carbon**, then sequestering that C in soil
Action in the root zone...

The rhizosphere fertility story requires an expanded cast of characters:

- Protozoa
- Nematodes
Protozoa

Also single celled, but more organized cell structure

Several times larger than bacteria

Consume bacteria, each other, some also consume fungi

Source: Soil and Water Conservation Society
Protozoa - Flagellates
Flagellates in Action under the Microscope

Video Credit - Tim Wilson, Microbe Organics
Other Protozoa in Action under the Microscope

Video Credit - Tim Wilson, Microbe Organics
Nematodes

- Microscopic unsegmented worms
- Many different kinds of nematodes
- Beneficial ones include those that eat bacteria and fungi, as well as the larger predatory nematodes that eat the smaller species

Source for both images: Soil and Water Conservation Society
Nematodes

Root feeders are the ones that cause plant damage. The latter can be controlled by the predatory nematodes if conditions for the predators are good.

From our microscope at an earlier workshop:
Underground Carbon Trading

Two basic systems:

1. **Plant root exudates**: Up to 44% of photosynthate exuded into rhizosphere

2. **Mycorrhizal fungi**: Two-way delivery system - nutrients traded for C compounds

Source: Soil and Water Conservation Society
Plant root exudates and fertility

- Plants “exude” up to half of their photosynthate into the soil from their roots.

- These “exudates” are substances rich in carbon, and therefore energy.

- Some of these substances have specific uses beneficial to the plant, such as disease prevention.

Bacteria on a plant root.
Plant root exudates and fertility - cont’d

- However --- most of the exudates become food for the microbes in the root zone, or “rhizosphere”

- This is known as the “rhizosphere effect” - much greater populations of microbes near roots because of these rich energy sources
Plant root exudates and fertility - cont’d

This “give-away” benefits the plant in many ways:

- **Nutrients:** predators are attracted to root zone because of the high density of prey (bacteria and fungi)
- The predators consume the prey and release plant-available nutrients as wastes, right where the plant needs them
- The high density of beneficial microbes also makes it more difficult for disease organisms to gain a foothold
AMF: Arbuscular Mycorrhizal Fungi

- Most common mycorrhizae in farm fields
- Many different species
- Confer many benefits, including: water and nutrients, disease suppression, soil structure, increased C levels
- Suppressed by high levels of fertility, especially P
- Damaged by tillage, inappropriate chemical use

Source: Soil and Water Conservation Society
Mycorrhizal connections to roots

Symbiotic association of Mycorrhizal fungi and the plant root (200x magnification)
The Biology of Soil Carbon

...and its connection to climate and resilience
Climate Regulation

How do soils sequester carbon?

- Used to be thought that soil carbon came solely from organic residues
- Therefore, to sequester carbon in soils -- leave residues, add manure, compost

Now understood that the C coming through plant roots (carbon trading system) is a key to higher sequestration

Source: Soil and Water Conservation Society
Climate Regulation (2)

How Fast Can Soils Sequester Carbon?

- IPCC estimates: 1.1 to 1.8 tonnes of CO$_{2e}$ per ha per year
- 2007 study for central Canada: 0.36 to 1.1 tCO$_{2e}$/ha/yr
- ECO report - Ontario farmer: 4.75 tCO$_{2e}$/ha/yr
- Similar (or higher) figures in anecdotal literature
- Recent study in southeastern US: 29 tCO$_{2e}$/ha/yr (degraded grazing land)

Why the difference?

US EPA has stated that the average car generates 4.7 tCO$_{2e}$/yr. Even at lowest IPCC estimate, a 500 ha farm would offsetting the GHG emissions of 117 cars annually. The 4.75 rate would offset the GHGs of 505 cars annually.
The Shifting Understanding of what Constitutes Soil Humus

- What exactly IS soil humus?
  - OM too tough for the bugs?
  - Huge organic molecules synthesized by either chemical or biological means?

- New understanding emerging:
  - Persistence of SOM as an ecosystem property
  - Does “soil humus” really exist in the way we have always thought? - Lehmann and Kleber - “Contentious Nature of SOM”

- Relevance to compost, composting, and climate change
  - Kallenbach 2016 - “Direct Evidence for Microbially Derived SOM formation and its ecophysiological controls”
Soils, Compost and Climate Change

The Soil Story

https://www.youtube.com/watch?v=08TI1RKj54g
Conclusion: Creating healthy soil ecosystems

--- concepts, principles, practices
Three Important Requirements of a Living Soil Ecosystem

Sufficient food/energy

A safe home (habitat)

Diversity
### Giving and Getting

<table>
<thead>
<tr>
<th>What Healthy Soil Gives Us:</th>
<th>What Soil Needs From Us to be Healthy:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water management</td>
<td>Energy/Food management</td>
</tr>
<tr>
<td>Nutrient management</td>
<td>Habitat protection</td>
</tr>
<tr>
<td>Disease &amp; pest suppression</td>
<td>Diversity management</td>
</tr>
</tbody>
</table>
Ecological Succession in Soils (and Compost)
Productivity in Different Stages of Succession

NPP, kcal/m²/year

- Swamp & Marshland
- Tropical Rain Forest
- Temperate Forest
- Northern Coniferous Forest
- Savannah
- Agricultural Land
- Woods and Shrubland
- Temperate Grassland
- Lakes & Streams
- Open Ocean
- Desert Scrub
- Extreme Desert

0 2000 4000 6000 8000 10000
BE A SOIL BUILDER

1. Cover the soil
2. Keep roots in the ground
3. Add organic amendments
4. Support plant & soil diversity
5. Minimize soil disturbance

This project was funded in part through Growing Forward 2 (GF2), a federal-provincial-territorial initiative. The Agricultural Adaptation Council assists in the delivery of GF2 in Ontario.
Compost: The Multi-Purpose Soil-Health BMP

- Compost as SFW probiotic -- *Marin Carbon project*
- Compost as biological crop protection product -- *numerous studies*
- Compost as promoter of succession in soils -- *BEAM*
- Compost as rhizosphere inoculant -- *Huma Terra*
Marin Carbon Project: NPP and Carbon Sequestration

UC Berkeley - Marin Carbon Project
- 4000 cu yds of food-waste compost on 100 acres of rangeland
- 50 per cent increase in forage production
- Increase of one tonne of C (3.7 t CO$_{2e}$) per ha per year for three years after single application

American Carbon Registry -
Developed offset protocol for application of compost to rangelands

NOTE: Soil C not from compost - it comes from the increased biomass production and the root exudates!
# Compost and Disease Suppression

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Crop</th>
<th>Organic Amend</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusarium spp</td>
<td>Various hosts</td>
<td>Veg Compost</td>
<td>Yogev et al 2006</td>
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<tr>
<td>Phytophthora cinnamomi</td>
<td>White lupin</td>
<td>Fresh &amp; composted chicken manure</td>
<td>Aryantha et al 2000</td>
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<tr>
<td>Pythium ultimum</td>
<td>Garden cress</td>
<td>Bark compost</td>
<td>Erhart et al 1999</td>
</tr>
<tr>
<td>Rhizoctonia soloni</td>
<td>Garden cress</td>
<td>Viticulture waste compost, cow manure compost</td>
<td>Pane et al 2007</td>
</tr>
<tr>
<td>Rosellinia necatrix</td>
<td>Avocado</td>
<td>Vegetal compost</td>
<td>Bonilla et al</td>
</tr>
<tr>
<td>Sclerotium rolfsii</td>
<td>Tomato</td>
<td>Vegetal compost</td>
<td>Bulluck and Ristaino 2002</td>
</tr>
<tr>
<td>Verticillium dahliae</td>
<td>Eggplant</td>
<td>Horse manure, municipal green waste, wood shavings</td>
<td>Malandraki et al 2008</td>
</tr>
</tbody>
</table>

Compost and Soil Health: BEAM

New scientific support for the idea that we can use compost to **improve F:B balance** of SFW

Dr. David Johnson, University of New Mexico, good results from increasing F:B ratio in compost
Compost and Soil Health: Huma Terra

<table>
<thead>
<tr>
<th>Crop and field</th>
<th>Treatment</th>
<th>Yield Bu/acre</th>
<th>Δ Yield</th>
<th>Net margin $/quarter (160 acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malting Barley</td>
<td>Humat HEHA3 in furrow</td>
<td>85.0</td>
<td>+12%</td>
<td>+4281</td>
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<tr>
<td></td>
<td>Control</td>
<td>76.0</td>
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<tr>
<td>Wheat</td>
<td>Humat HEHA3 spread</td>
<td>50.1</td>
<td>+18%</td>
<td>+4505</td>
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<tr>
<td></td>
<td>Control</td>
<td>42.4</td>
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<tr>
<td>Wheat</td>
<td>SE Comp1</td>
<td>66.8</td>
<td>+32%</td>
<td>+13095</td>
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<tr>
<td></td>
<td>Control</td>
<td>50.7</td>
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<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>Humat H1CL spread</td>
<td>72.7</td>
<td>+17%</td>
<td>+7282</td>
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<tr>
<td></td>
<td>Control</td>
<td>62.3</td>
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<tr>
<td>Oat</td>
<td>SE Comp2 furrow</td>
<td>108.8</td>
<td>-3%</td>
<td>Even (Nearly same yield with only 50% NP)</td>
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<td>Control</td>
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<td>Flax</td>
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<td>+3879</td>
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<tr>
<td></td>
<td>Control</td>
<td>25.1</td>
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</tbody>
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[https://www.humaterra.org](https://www.humaterra.org)
Thank you!

gmunroe@compost.org