<table>
<thead>
<tr>
<th>Functional group</th>
<th>Function</th>
<th>Representative members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Engineers</td>
<td>Regulate 90% of energy flow in soil</td>
<td>Soil microbes (bacteria, archaea, fungi, protozoa)</td>
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<td>Ecosystem Engineers</td>
<td>Build pore networks and aggregates</td>
<td>Plant roots, earthworms, and other larger invertebrates (e.g., millipedes, centipedes, beetles, caterpillars, scorpions)</td>
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Turbo et al., 2010

Rudy Garcia
Regional Soil Health Specialist (AZ, CO, NM, UT)
Natural Resources Conservation Service
### Functional group

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<td>Build pore networks and aggregates, Redistribute soil particles, microbes, &amp; organic matter</td>
<td>Plant roots, earthworms, and other larger invertebrates (e.g., millipedes, centipedes, beetles, caterpillars, scorpions)</td>
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</tbody>
</table>

Turbe et al., 2010
Every trophic level must function for the soil food web to function!

Soil is a Living Factory

- Macroscopic and microscopic organisms need:
  - Food
  - Water
  - Shelter
  - Habitat
  - Powered by sunlight
Soil Organic Matter

Labile Organic Matter
Rapid Turnover

Biomass
Living Organisms

Detritus
Free Identifiable dead plant material

Particulate OM
Free partially degraded plant material

Free or dissolved biomolecules, degradation products

Humus
Protected or Slow Turnover C

Particulate OM
Protected bits of plant mat. & microbial cell walls

Protected biomolecules, degradation products

Char
Black aromatic products of fire

*Protected on clay surfaces, soil aggregates and in ultramicropores

A Biological Primer is a diverse cover crop mix that enhances the life and function of the soil.

**Build SOM & Regenerate Soil with Cover Crops**

**How Cover Crops Build Soil Health**

- Add Organic Matter
- Add Plant Diversity
- Enhance Mycorrhizal numbers
- Build Aggregates
- Increase Earthworms
- Add Lasting Residue/Cover
- Suppress Weeds
- Increase Infiltration of Water
- Reduce Erosion
- Minimize & Reduce Soil Compaction
- Manage Soil Moisture
- Capture & Recycle Nutrients (decrease nutrient loss)
- Attract Beneficial Insects
- Disease Mgt./Suppression
- Enhance Pollinators
- Support Wildlife
- Catch Snow
- Sunflower 1 lb
- Soybean 15 lbs
- Cowpea 10 lbs
- Turnip 1 lb
- Radish 2 lbs
- Proso Millet 3 lbs
- Pearl Millet 3 lbs
- Corn 1 lb
- Squash 1 lb
- Canola 1 lb

**Cool Season Cover crop**

- Barely
- Oat
- Lentil or Vetch
- Pea
- Clover, Crimson
- Radish
- Canola or Rape
- Turnip

**Warm Season cover Crop**

- Pearl Millet
- Sudangrass
- Buckwheat
- Safflower
- Radish
- Turnip
- Canola
- Spring Lentil
- Pea
- Crimson Clover

**Other Benefits:** Clean Air, Clean Water, Healthy & Nutritious Plants, and much more.
Plan on Diversity

- What crop types do you lack?
  - Cool season grass
  - Warm season grass
  - Cool season broadleaf
  - Warm season broadleaf
- Multi-species always better
  - Remember nature!
- Soil foodweb does better on diverse diet

Cover Crop Role in Diversity

1. Allow you to look at cropping periods rather than years
2. Can be used to accelerate rejuvenating soil health
3. Getting 4 to 6 weeks of growth is adequate to get the “rotation” effect!
4. Will increase soil biological diversity “Diversity above = diversity below”
**Johnson-Su No-Turn Composting Bioreactor**

- Reduces water usage by a factor of 6 times
- Reduces composting time by 66%
- Results in a low salinity compost (~2-3 mS/cm)
- Amenable to incorporation of vermicomposting after thermophilic phase (observed 10X N increase in end product)

**Johnson/Su Static Composting Technology**

- Produces a **Fungal Dominant** compost

**Results After 3.5 years of Enhancing Soil Microbiology (7 successive crops)**

- Control
- Compost

David C. Johnson, NMSU Institute for Sustainable Agricultural Research (ISAR)
davidcjohnson@nmsu.edu
Increased Soil Carbon Use Efficiency
Comparing plant growth to treatment Fungal:Bacterial ratio resulted in a good correlation with an $r^2 = 0.876$.
Many soil health innovators realize that cover crops can be more than providing cover, they are biological primers that jump start the revitalization of the degraded soil ecosystem.

**Cover Crop Chart**

<table>
<thead>
<tr>
<th>GROWTH CYCLE</th>
<th>PLANT ARCHITECTURE</th>
<th>RELATIVE WATER USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A = Annual</td>
<td>Upright</td>
<td>= Low</td>
</tr>
<tr>
<td>B = Biennial</td>
<td>Upright-Spreading</td>
<td>= Medium</td>
</tr>
<tr>
<td>P = Perennial</td>
<td>Prostrate</td>
<td>= High</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>COOL</th>
<th>---</th>
<th>BROADLEAF</th>
<th>WARM</th>
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<tbody>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>GRASS</th>
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<tbody>
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</tbody>
</table>
The Influence of Functional Diversity and Composition on Ecosystem Processes

Why Diverse Cover Crop Mixes?

1. If *Soil Health* is the goal, *Crop Diversity* cannot be ignored or overstated.
2. Plants were created to grow in diverse ecosystems.
3. Resilience comes from *Diversity*.
5. Balance: because even good things (legumes, brassicas) when not used in moderated balance can be harmful.
Utilize energy efficiently - understand the power of diversity: **Collaboration** is more apparent than **Competition**: ND case study: 2006 Production On Burleigh District Plot with 1.8 in. of rain

![Graph showing Lbs./dry matter/plot for different plots including Lupin Plot, Oil Seed Radish, Pasja Turnip Plot, Purple Top Radish, Cow Pea Plot, Cocktail Mixture 1/2, and Cocktail Mixture full. The values range from 0 to 5000 lbs. with varying heights for each plot.](image-url)
Very useful resources for planning & managing cover crops & building Soil Health

Resources
- Burleigh County Soil Conservation District
  http://www.bcscd.com/?id=23
- Managing Cover Crops Profitably
  www.sare.org/publications/covercrops.htm
- Overview of Cover Crops and Green Manures
Managing Cover Crops to Feed Soil Microorganisms

- **C:N ratio 24:1 Ideal for Microbes**
  - Higher C:N
    - Microbes don’t get enough N result in tying up N
    - Residue doesn’t decompose
    - Accumulates on the surface
    - Microbe populations decline
  - Lower C:N
    - Microbes get excess N result in N being available
    - Residue decomposes quickly
    - Microbe population explode then die off

- Need to Balance C:N through cover crop mixes

---

C:N Ratio for Various Crops

<table>
<thead>
<tr>
<th>Material</th>
<th>C:N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>rye straw</td>
<td>82:1</td>
</tr>
<tr>
<td>wheat straw</td>
<td>80:1</td>
</tr>
<tr>
<td>oat straw</td>
<td>70:1</td>
</tr>
<tr>
<td>corn stover</td>
<td>57:1</td>
</tr>
<tr>
<td>rye cover crop (anthesis)</td>
<td>37:1</td>
</tr>
<tr>
<td>pea straw</td>
<td>29:1</td>
</tr>
<tr>
<td>rye cover crop (vegetative)</td>
<td>26:1</td>
</tr>
<tr>
<td>mature alfalfa hay</td>
<td>25:1</td>
</tr>
<tr>
<td>Ideal Microbial Diet</td>
<td>24:1</td>
</tr>
<tr>
<td>rotted barnyard manure</td>
<td>20:1</td>
</tr>
<tr>
<td>legume hay</td>
<td>17:1</td>
</tr>
<tr>
<td>beef manure</td>
<td>17:1</td>
</tr>
<tr>
<td>young alfalfa hay</td>
<td>13:1</td>
</tr>
<tr>
<td>hairy vetch cover crop</td>
<td>11:1</td>
</tr>
<tr>
<td>soil microbes (average)</td>
<td>8:1</td>
</tr>
</tbody>
</table>

- Cover crops added to a cash crop rotation can help manage nitrogen and crop residue cover in a cropping sequence.
- A low C:N ratio cover crop containing legumes (pea, lentil, cowpea, soybean, sunn hemp, or clovers) and/or brassicas (turnip, radish, canola, rape, or mustard) can follow a high C:N ratio crop such as corn or wheat, to help those residues decompose, allowing nutrients to become available to the next crop.
- Similarly, a high C:N ratio cover crop that might include corn, sorghum, sunflower, or millet can provide soil cover after a low residue, low C:N ratio crop such as pea or soybean, yet decompose during the next growing season to make nutrients available to the following crop.
- Understanding carbon to nitrogen ratios of crop residues and other material applied to the soil is important to manage soil cover and crop nutrient cycling.
- Providing quality habitat for soil microorganisms should be the goal of producers interested in improving soil health.
- Soil is a biological system that functions only as well as the organisms that inhabit it.
Higher Soil Organic Matter (Quantity & Quality)

Roles of the three “categories” of organic matter in soils:

**Living** - Alive organisms. Create stable organic matter and...
1. plant roots: make pores, feed soil life, allelochemicals
2. soil organisms: make nutrients available, suppress disease, produce plant growth promoting hormones, aggregate soils...

**Dead** - Recently dead organisms and crop residues. Also called “active” or “particulate” organic matter.
1. Feed soil organisms. Help do all above!
2. On surface: maintain soil moisture, prevent erosion.

**Very Dead** - Well decomposed organic materials.
1. High amounts of negative charge holds nutrients.
2. Has high water-holding capacity.
3. Stores (sequesters) C.

---

**Value of Soil Organic Matter**

Assumptions: 2,000,000 pounds soil in top 6 inches
1% organic matter = 20,000#

**Nutrients:**
- **Nitrogen:** 1000# * $0.50/#N = $500
- **Phosphorous:** 100# * $0.70/#P = $70
- **Potassium:** 100# * $0.50/#K = $50
- **Sulfur:** 100# * $0.50/#S = $50
- **Carbon:** 10,000# or 5 ton * $?/Ton = $0

Value of 1% SOM Nutrients/Acre = $670

Original Jim Kinsella/Terry Taylor (2006)/revised Jim Hoorman (2011)

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Diagram by Dr. Rafiq Islam
Particulate Organic Matter

Particulate organic matter (POM) fraction referred to in this document comprises all soil organic matter (SOM) particles less than 2 mm and greater than 0.053 mm in size (Cambardella and Elliot, 1992). POM is biologically and chemically active and is part of the labile (easily decomposable) pool of soil organic matter (SOM). Figure 1 shows tiny debris of POM (0.25 mm < POM size < 0.5 mm) at different stages of decomposition isolated from soil under no-till management. Studies have shown that POM accounts for few to large amounts of soil C (20% and more) in some soils of Eastern Canada and the USA depending upon agroecosystems and management practices.
Plant Succession Ladder as a Function of Fungal:Bacterial Ratio (F:B)

Where we need to be!

- **F:B = 100:1 to 1000:1** → Conifer, Old Growth Forests
- **F:B = 5:1 to 100:1** → Deciduous Trees
- **F:B = 2:1 to 5:1** → Shrubs, Vines, Bushes
- **F:B = 1:1** → Late Successional Grasses, Row Crops
- **F:B = 0.75** → Mid-grasses, Vegetables
- **F:B = 0.3** → Early Grasses, Bromus, Bermuda
- **F:B = 0.1** → Weeds (High NO₃, Lack of Oxygen)
- **F:B = 0.01** → Cyanobacteria, True Bacteria, Protozoa, Fungi, Nematodes
- **100% Bacterial** → Bare Soil Parent Material

Where we are currently in agroecosystems!

Elaine Ingham- www.soilfoodweb.com

David C. Johnson- NMSU Institute for Sustainable Agricultural Research (ISAR)
davidcjohnson@nmsu.edu

New Mexico State University
**ecological succession** - (ecology) the gradual and orderly process of change in an ecosystem brought about by the progressive replacement of one community by another until a stable climax is established.

- Natural succession occurs in a plant community and soil communities.
- Soil that is on the low successional side tends to be dominated by bacteria has high pH and nitrate-nitrogen - a preferred environment for low successional plants (weeds).
- Soil on the high successional side have a balanced soil food web, release nutrients in an environment better suited for higher plants.
- Each step in the successional process leads towards a steady state community but is held back by natural or man induced disturbance.

**Characteristics of a Steady (Stable) State Ecosystem**
- Low disturbance
- High diversity in plants, animal and soil biota
- Require low human inputs
- Have highly functioning eco-services, e.g. nutrient cycling, regulating water and diverse soil food web

**Characteristics of an early stage successional ecosystem (farm or ranch)**
- High disturbance, e.g. physical, chemical and/or biological
- Low diversity (monoculture)
- Require high human inputs
- Have disrupted or non-functioning eco-services
Soil organic matter (SOM) is <6% of soil by weight but controls >90% of the function.

Density of SOM: 0.6 g/cm²  Density of Soil: 1.45 g/cm²

SOM has less density than soil so it has more space for air and water storage.

SOM is negatively charged, but binds both cations and anions.

Every Pound SOM holds 18-20# of Water!

As soil organic matter increases from 1% to 3%, the available water holding capacity of the soil doubles (Hudson, 1994).

The majority of the SOM is present in the top 10 cm of soil.

<table>
<thead>
<tr>
<th>Percent SOM</th>
<th>Sand</th>
<th>Silt Loam</th>
<th>Silty Clay Loam</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>1.9</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>2.4</td>
<td>1.8</td>
</tr>
<tr>
<td>3</td>
<td>1.7</td>
<td>2.9</td>
<td>2.2</td>
</tr>
<tr>
<td>4</td>
<td>2.1</td>
<td>3.5</td>
<td>2.6</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>4.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Inches of Water/One Foot of Soil

1 acre inch = 27,150 gallons of water

Water storage depends on texture, organic matter, and aggregation.
Soil Humus (Humic & Nonhumic substances): That more or less stable fraction of the soil organic matter remaining after the major portions of added plant and animal residues have decomposed. Usually it is dark in color. About 20-30% of humus in soils consists of nonhumic substances (e.g., polysaccharides). These substances are less complex & less resistant to microbial attack than those of the humic group. Some of these nonhumic substances are microbiologically modified plant compounds, while others are compounds synthesized by soil microbes as by-products of decomposition. Humic Substances include Humin (highly condensed, complexed with clay), Humic acids and Fulvic acids. All three groups of humic substances are relatively stable in soils. 

Soil Organic Carbon Gains and Losses Guide

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