Understanding Soil Health
Farming in the 21st Century
a practical approach to improve Soil Health

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Agronomist
ENTSC
Why in Now?

- World population is estimated to be at 9.1 billion by 2050
- To sustain this level of growth, food production will need to rise by 70 percent
- Between 1982-2007, 14 million acres of prime farmland in the U.S. was lost to development
- Energy demands
  - Increase use of biofuels (40% of corn used for ethanol)
  - Increase use of fertilizer (use of Anhydrous up 48%, Urea up 93%)
Is the Buffer working?
6 /2007

Lubbock Texas Oct. 17,2011

Erosion from bare fields
5/2007
Soil Health What is It?

- The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans
  - Nutrient cycling
  - Water (infiltration & availability)
  - Filtering and Buffering
  - Physical Stability and Support
  - Habitat for Biodiversity
The Soil Food Web

Is complex

Every trophic level must function for the soil food web to function!
Soil is a Living Factory

- Macroscopic and microscopic organisms
  - Food
  - Water
  - Shelter
  - Habitat
  - Powered by sunlight

- Management activities improve or degrade soil health
  - Tillage
  - Fertilizer
  - Pesticides
  - Grazing
  - Plant Diversity
What can Soil Organisms Do?

- Improve Soil Aggregation/Strength
- Improve Water Holding capacity
- Improve Nutrient Cycling
- Improve Infiltration
- Reduce pest problems
<table>
<thead>
<tr>
<th></th>
<th>Crop Land</th>
<th>Prairie</th>
<th>Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>100 mil. - 1 bil.</td>
<td>100 mil. - 1 bil.</td>
<td>100 mil. - 1 bil.</td>
</tr>
<tr>
<td>Fungi</td>
<td>Several yards</td>
<td>10s – 100’s of yds</td>
<td>1-40 miles (in conifers)</td>
</tr>
<tr>
<td>Protozoa</td>
<td>1000’s</td>
<td>1000’s</td>
<td>100,000’s</td>
</tr>
<tr>
<td>Nematodes</td>
<td>10-20</td>
<td>10’s – 100’s</td>
<td>100’s</td>
</tr>
<tr>
<td>Arthropods</td>
<td>&lt; 100</td>
<td>500-2000</td>
<td>10,000-25,000</td>
</tr>
<tr>
<td>Earthworms</td>
<td>5-30</td>
<td>10-50</td>
<td>10-50 (few in conifers)</td>
</tr>
</tbody>
</table>
Fantastic Voyage into the Rhizosphere
vascular-arbuscular mycorrhizal (VAM) fungi

Rhizosphere

Dennis Froemke
ND Area Range Specialist
Rhizosphere
Where Roots Meet Soil

Zone of Concentrated Biological Activity
- Bacteria
- Fungi
- Protozoa
- Nematodes
BACTERIA - Functions

- Decompose Organic Matter
- Keeps Nutrients in the Root Zone and Out of Water
- Enhance Soil Structure by making some “glues”
- Competes with Disease Causing Organisms
- Filters and Degrades Pollutants
- Actinomycetes (filamentous bacteria) – Soil Smell
- Feed other members of the food web (Prey)
Fungi - Functions

- Decompose carbon compounds
- Improve OM accumulation
- Retain nutrients in the soil
- Bind soil particles with Glomalin
- Mycorrhizal fungi – Associate with Plants
- Compete with plant pathogens
- Food for the rest of the food web
What is GLOMALIN?

- Glycoprotein (Sugar Protein)
  - 4-6% sugar
- Coats and protects hyphae
- Heat and enzymatically stable
- Complex structure
- Hyperaccumulate iron and other metals
  - 0.5 to 7% iron
- Hydrophobic interactions
- Deposited on organic matter and soil particles

Hyphae from a pot culture of *Gi. gigantea* at 90X under bright field.

Same picture, except under fluorescence.
PROTOZOA-(Predator)
Flagellates-Amoebae-Ciliates

- Single Celled Animals
- Feed on Bacteria and Release Nutrients (N)
- Increase Decomposition Rates
- Food Source for Other Soil Organisms
- Prevent some Pathogens From Establishing on Plants
- Need Soil Moisture to Move
NEMATODES

Non-Segmented Worms

Most are Good for the Soil and Plants

• Regulate Populations of Other Organisms
• Mineralize Nutrients into Plant-Available Forms
• Consume Disease Causing Organisms
• Distribute Bacteria and Fungi Through the Soil Along Plant Roots
• Provide a Food Source for Other Organisms
Drilosphere: Zone of earthworm influence

- Redistributes plant litter "Carbon" throughout the soil the profile
- Soils are enriched with N, P, and humified organic matter
- Increase water infiltration
- Provide a bio pore for plant roots
- Homogenize soil surface
- Increase bio-diversity in soils

Nature’s residue managers
Soil Health
Planning Principles

• Manage more by Disturbing Soil Less
• Use Diversity of Plants to add diversity to Soil Micro-organisms
• Grow Living Roots Throughout the year
• Keep the Soil Covered as Much as Possible

Goal: To create the most favorable habitat possible for the soil food web
Disturbance: What things change when you stop tilling the soil?

- Soil pores remain continuous
- Soil aggregates form and are not destroyed
- Soil Food Web increases and diversifies
- Weed seeds are not planted
- Water is captured and stored
- Bulk density decreases
- Soil fungi and earthworms increase
- Microarthropods increase (>20% of nutrient cycle)
Agricultural Disturbance Destroys the “Soil Spheres”

PHYSICAL DISTURBANCE: Tillage induces the native bacteria to consume soil carbon; byproduct is CO$_2$.
The primary factors controlling microbial activity vary with time + SOM.

Which tillage system has more microbial activity?

- Soil respiration in CT system
- Soil respiration in NT system

Havlin et al. (1999)
Soil Health Principle

Grow Living Roots Throughout the Year

Benefits:

- Increases microbial activity influences the N mineralization and immobilization
- Increases plant nutrient/vitamin uptake/ concentrations with mychorrhizal and bacteria associations
- Increases biodiversity and biomass of soil organisms
- Improves physical, chemical and biological properties of soils
- Sequesters and redepots nutrients
- Increases OM
Biomass Production
Annual Cropping Systems

Missed opportunities for resource assimilation and dry matter production

Dry matter production or resource loss (mass/time)

Annual grain crop

Winter cover crop

Spring Summer Autumn Winter

Additional opportunities for resource losses

after A.H. Heggenstaller

A. H. Heggenstaller, University of Alberta
Soil Health Principle

Keep it Covered as Much as Possible

Benefits:

• Control Erosion
• Protect Soil Aggregates
• Suppresses Weeds
• Conserves Moisture
• Cools the Soil
• Provides Habitat for Soil Organisms
Soil Temperatures

- Conserve moisture and reduce temperature.
- Crop yields are limited more often by hot and dry, not cool and wet.
When soil temperature reaches

- **140 F**: Soil bacteria die
- **130 F**: 100% moisture is lost through evaporation and transpiration
- **113 F**: Some bacteria species start dying
- **100 F**: 15% moisture is used for growth; 85% moisture lost through evaporation and transpiration
- **95 F**: 100% moisture is used for growth
- **70 F**: 100% moisture is used for growth

J.J. McEntire, WUC, USDA SCS, Kernville TX, 3-58 4-R-12198. 1956
Why do we still have a thicker layer of snow on the plot under CT than in NT?
Soil Health Principle

Use Diversity of Plants to add diversity to Soil Organisms

- Plants interact with particular microbes
  - Trade sugar from roots for nutrients
- Microbes convert plant material to OM
- Requires a diversity of plant carbohydrates to support the variety of microbes
- Lack of plant diversity will drive system to favor some microbes more than others
How to Increasing Diversity in a Crop Rotation

• Lengthen the rotation by adding more crops
  – Increases soil organic matter
  – Breaks pest cycles
  – Improves nutrient utilization and availability
  – Utilize available water deeper in the soil profile
  – Provide windows for management
    • spread manure
    • Plant & harvest crops

• Add more plants in the current crop rotation
  – Utilize cover crops during non-cropping part of the year
Simplified Crop Classification

- Plant morphology
  - Broad leaf
  - Grasses

- Plant growth habits
  - Cool season
  - Warm season
Crop Classification Warm Season

Grasses
- Corn
- Millet
- Sudan

Sudex
- Sorghum

Broadleaf
- Alfalfa
- Soybean
- Buckwheat

Chick pea
Cow pea
Sunflower
Crop Classification Cool Season

Grasses
- Barley
- Rye

Triticale
- Wheat

Broadleaf
- Canola
- Clovers
- Mustards

Pea
- Radish
- Turnips
The Influence of Functional Diversity and Composition on Ecosystem Processes

David Tilman, * Johannes Knops, David Wedin, Peter Reich, Mark Ritchie, Evan Siemann
The Influence of Functional Diversity and Composition on Ecosystem Processes
Mixture of cereal rye, hairy vetch, and field peas as a winter cover crop

Mixture of cereal rye, hairy vetch and crimson clover
## 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><strong>Ideal Microbial Diet</strong></td>
<td><strong>24:1</strong></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>

### Rye
- High C:N
- Ties up N
- Compounds problem following another high C:N crop

### Hairy Vetch
- Low C:N
- Release lots of N
- Decomposes Fast

### Rye & Hairy Vetch Mix
- Balance C:N ratio
- Control decomposition
- Ideal cover crop mix
Hard to believe that the same results can be achieved using simpler biological methods!!!
All Plots Harvested October 18, 2011

190 bu/ac corn grown with zero N input at planting

Cover Crop Economics
All Data is Per Acre Except Where Noted

Nitrogen input:
60/40 blend of Super U and Ammonium Sulfate, at $0.795 / lb

- 190.8 bu/ac Zero Units / N
- 205.6 bu/ac 60 Units / N
- 198.1 bu/ac 90 Units / N
- 196.9 bu/ac 120 Units / N
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
This soil is naked, hungry, thirsty and running a fever!

Ray Archuleta 2007
Agricultural soils do not have a water erosion/runoff problem, they have a water infiltration problem.
Is the Buffer working?

Erosion from bare fields

5/2007

Gabe Brown ND

Ray McCormick IN

Steve Groff PA

Dave Brandt OH

Ray Styer NC

Ray McCormick IN

Gabe Brown ND
SOM’S Revolving Nutrient Bank Account.

- A furrow slice is 6 7/8 inches = 2,000,000 lbs of soil per acre.
- 1.0% SOM X 2,000,000 lbs = 20,000 lbs of SOM per acre.
- 1.0% SOM = approximately 10,000 lbs Carbon, 1,000 lbs Nitrogen, 100 lbs Phosphorous, and 100 lbs of Sulfur.
- Mineralization Rate = 2-3% from Organic N to Inorganic N, which does not stop at harvest time.
## Soil Organic Matter and Available Water Capacity

**Inches of Water/One Foot 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>

Berman Hudson  
*Journal Soil and Water Conservation 49(2) 189-194*  
March – April 1994  
Summarized by:  
Dr. Mark Liebig, ARS, Mandan, ND  
Hal Weiser, Soil Scientist, NRCS, Bismarck, ND
I'm going to say a few words about soil health. I can't stand it. I've got to say something.

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