Systems Approach to Soil Health

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What is Soil Health (Quality)?

• Ability of the soil to support crop growth ... (Power & Myers, 1989)

• Capacity of the soil to function in a productive and sustained manner ... (NCR-59 Madison WI, 1991)

• The capability of the soil to produce safe and nutritious crop .... (Parr et al., 1992)

• Fitness for use (Pierce & Larson 1993)
What is expected of a healthy soil

- Nutrient retention and release,
- Partitioning of rainfall into runoff and infiltration
- Moisture retention and release
- Resistance to environmental degradation
- Buffering environmental pollutants
- Maintain bio-diversity (nutrient cycling/uptake)
Approach to Soil Health

Soil Health

Chemical

Biological

Physical
Soil Health Indicators

**Physical**
- Bulk density
- Penetration resistance
- Aggregate stability
- Water infiltration rate
- Water holding capacity
- Pore size distribution

**Chemical**
- Cation exchange capacity
- N, P, K
- Salinity
- Micronutrients
- [Toxins, pollutants]

**Biological**
- Soil disease suppressive capacity
- Beneficial and pathogenic nematodes, [other pathogens]
- N mineralization rate (PMN)
- Decomposition rate
- Respiration rate
- Earthworm counts
- % OM
- “Active” C, N in OM
Physical Issues

- **Aggregation** – how well the soil binds together
- **Water Retention** – how much water the soil can retain
- **Compaction** – how tightly the soil is packed together
Physical aspects of soil health

**Aggregation** affects

- Soil erosion by water and wind
- Pore size distribution (water movement/retention)
- Drought tolerance of soils
- Root growth and proliferation
- Soil aeration
Management makes the difference

32 Years

Residue left on surface – Corn Grain

Residue taken away – Corn Silage

4 inches depression
Physical aspects of soil health

Compaction affects

- Water movement
- Water holding capacity
- Root growth and proliferation
- Soil aeration
Roots in loose or compacted soil
Soil Compaction

- Surface crusting
- Plow layer compaction
- Subsoil compaction
Compaction alters the status of soil water

Well-structured soil

- **Drought stress**
  - Small pores
  - Medium pores
  - Large pores

Optimum water range

Adequate aeration

Good drainage

Field capacity

Compacted soil

- **Root resistance**
  - Drought Stress
  - Small pores

Optimum water range

Poor aeration

Poor drainage

Soil water status

- Very dry
- Saturation

Compaction alters the status of soil water
Penetration Resistance

**Definition:** The resistance of a soil to root growth

**Affected by Density of Soil:**
Low Bulk Density and high porosity make soil easy to penetrate

**Affected by Moisture:**
the wetter, the softer!
Compaction

Damage is greatest
• when soils are wet
• when loads are high
Chemical aspects of soil health

– Nutrient sufficiency
– Soil salinity levels/Sodium issues
– Water salinity levels
Resolving Chemical Issues

Soil Testing is Important !!!

– Helps to know what is in your soil
– Helps to plan how much of nutrients to apply
– Nutrient needs vary with soil and crop
– Helps to know if your soil is building up salts
– Will let you know if your management is improving, degrading or maintaining your soil
Biological aspects of soil health

– Soil Organic Matter
– Soil Microbial Activity
– Diversity of Flora and Fauna
– Soil Nitrogen Mineralization
– Organic Matter Decomposition
– Soil Borne Pathogens
Adding organic matter results in many changes.

- Increased biological activity (& diversity)
- Decomposition
- Aggregation increased
- Nutrients released
- Harmful substances detoxified
- Humus and other growth promoting substances
- Improved porosity and soil structure
- Improved tilth and water storage
- Reduced soil-borne diseases, parasitic nematodes
- Improved tilth and water storage

**HEALTHY PLANTS**

Modified from Drinkwater and Oshins, 1998.
Types of organic matter

- Living organisms (<5%)
- Fresh residue (<10%)
- Stabilized organic matter (humus) (33% - 50%)
- Decomposing organic matter (active fraction) (33% - 50%)
- Very Dead
- Dead
Organic Matter

—Living—

organisms of various sizes such as bacteria, fungi, nematodes, earthworms, mites, springtails, moles, etc.

plant roots
Soil Biology

Soil is very busy and full of life!!!

A very small portion of soil

Life in the soil

- Plant root hair
- Bacterial colonies
- Mycorrhizal hyphae
- Actinomycete hyphae and spores
- Decomposing plant cells
- Nematode
- Flagellate
- Ciliate
- Amoeba
- Microarthropods
- Clay organic matter complex
- Fungal hyphae and spores

Modified drawing by S. Rose and E.T. Elliott
Soil Organisms

In one teaspoon of soil

- Bacteria: 100 million to 1 billion
- Fungi: 6-9 ft fungal strands put end to end
- Protozoa: Several thousand flagellates & amoeba
  One to several hundred ciliates
- Nematodes: 10 to 20 bacterial feeders and a few fungal feeders
- Arthropods: Up to 100
- Earthworms: 5 or more
Healthy soils maintain a diverse community of soil organisms that:

• Suppress plant disease, and insect and weed pests;

• Form beneficial symbiotic associations with plant roots
  – Mycorrhizae, Rhizobium

• Recycle essential plant nutrients

• Improve soil structure for water and nutrient retention

• Ultimately, increase grower profits and protect the environment
Nitrogen Fixation Through Legumes (making nitrate-N available to crops)

- Examples of legumes are alfalfa, clovers, beans
- Bacteria that make nitrate in plant roots with plants are called Rhizobium
- Nitrogen come from the soil air (79% N$_2$ in soil)
- It is a relationship of give and take
- Plants supply bacteria with food and bacteria gives back nitrate to plants

Symbiotic = up to 270 lb N/ac/year
Non-symbiotic = up to 20 lbs N/ac/year
Sesbania Nodules

- Sesbania used as green manure in an organic rotation experiment
### Potential of legumes to add N to Soil

<table>
<thead>
<tr>
<th>Cover Crop</th>
<th>C:N</th>
<th>Nitrogen (lb N/ac)</th>
<th>Biomass (t/ac)</th>
</tr>
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<tbody>
<tr>
<td>Sesbania</td>
<td>25</td>
<td>248</td>
<td>7.3</td>
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<tr>
<td>Cowpea I&amp;C</td>
<td>15</td>
<td>221</td>
<td>3.7</td>
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<tr>
<td>Lablab</td>
<td>14</td>
<td>192</td>
<td>3.3</td>
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<tr>
<td>Cowpea CA</td>
<td>12</td>
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<tr>
<td>Cowpea CC36</td>
<td>18</td>
<td>150</td>
<td>2.9</td>
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<tr>
<td>Bush bean</td>
<td>10</td>
<td>146</td>
<td>1.9</td>
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<tr>
<td>Pigeon Pea</td>
<td>10</td>
<td>131</td>
<td>1.6</td>
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<tr>
<td>Guar Durga</td>
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<td>124</td>
<td>2.3</td>
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<td>Tepary Bean</td>
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<td>120</td>
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<tr>
<td>Lima Bean</td>
<td>12</td>
<td>119</td>
<td>1.8</td>
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<tr>
<td>Green Bean</td>
<td>15</td>
<td>82</td>
<td>1.5</td>
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<td>Guar Evergreen</td>
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<td>79</td>
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<tr>
<td>Moth Bean</td>
<td>15</td>
<td>69</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Summer green legume experiment conducted in Las Cruces, NM under irrigated system*
Biological activity in a sandy soil as a function of tillage

Phosphatase activity (μg p-NP g⁻¹ soil h⁻¹)

Direct planting on permanent soil cover
Plowing

Recently dead soil organisms and crop residues provide the food (energy and nutrients) for soil organisms to live and function. Also called “active” or “particulate” organic matter.
Active Fraction

- 10 to 30% of the soil organic matter (active fraction) is responsible for maintaining soil microorganisms.
- The active fraction of organic matter is most susceptible to soil management practices.

Soil Organic Matter Continuum

- Easily decomposed
- Green manure
- Compost
- Resistant to decomposition
- Humus

ACTIVE
Active Carbon Measurement

- Permanganate Oxidation Technique
- Potassium permanganate oxidizes the active fraction of the soil organic matter
- Potassium permanganate is purple – the purple color decreases in intensity as more carbon is oxidized
- Intensity of the color can be measured with a spectrometer
Organic Matter
—Very Dead—

Well decomposed organic ➔ **Humus**
Humus contains very high amounts of negative charge
Stable Organic Matter - Humus

- Cation nutrients are held on negatively charged organic matter and clay

- a) cations held on humus
- b) cations held on clay particle
- c) cations held by organic chelate
Stable Organic Matter - Humus

• Thus, soil organic compounds become stabilized and resistant to further changes by microorganisms.

• Stabilized organic matter acts like a sponge and can absorb 2-6 times its weight in water.
Improving Soil Health

• Long-term Thinking and Strategy

Basic Methods (Toolbox)

- Tillage Management (Reducing tillage)
- Organic Matter Management
- Cover Cropping
- Crop Rotation
- Integrated diseases and pest management
- Soil amendments
Merits/demerits of using proprietary products from different vendors

• Beware of “magical products”
• Query the science of the product
• Ask for University research on the product
• If you are convinced of the science, test out the product in a way that you can see the difference
• Evaluate the cost to benefit ratio of the product, especially those that need to be applied yearly
Reduced Tillage Goals

- Enhance soil quality
  - Conserve soil organic matter
  - Conserve soil moisture
- Reduce erosion
- Reduce fuel use
- Optimize weed control
- Maintain yields
Reduced Tillage Facts

- Depends on equipment (capital intensive)
- Depends on crop (works better for large seeds)
- Little difference between full width tillage and reduced tillage in terms of yield (Short-term)
- Labor savings during early season field prep.
- Investment in Long Term Soil Health
No-till wheat after corn silage
Vado, NM
Strip-till after corn silage
Vado, NM
Comparing Costs between Tillage Systems

<table>
<thead>
<tr>
<th>Reduced Tillage (Strip Tillage)</th>
<th>Conventional Tillage (Plow + Disking)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-plant Herbicide</td>
<td>$7.31</td>
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<tr>
<td>Strip Tillage</td>
<td>$14.06</td>
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<tr>
<td>Planting</td>
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<tr>
<td>TOTAL</td>
<td>$33.37</td>
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<tr>
<td></td>
<td>Plow, disk harrow</td>
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<td></td>
<td>$30.50</td>
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<tr>
<td></td>
<td>Planting (6 row)</td>
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<tr>
<td></td>
<td>$12</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
</tr>
<tr>
<td></td>
<td>$42.50</td>
</tr>
</tbody>
</table>

2004 Study
Hidden savings with Reduced tillage

- Timeliness of farm operation
- Reduced wear and tear of farm equipment
- Reduced pesticide and fertilizer rates ???
  - Lower N due to soil health improvement?
- Possibly higher yields in the long-run
Strip tillage

- Land preparation in strips
- Tillage width depend on system
- Only 1 field pass prior to seeding
Strip Tiller – 2 Row Unit
Conventional tillage
- Primary, secondary tillage, seedbed preparation
- 2-4 field tillage passes
- ‘Clean Field’

Permanent No-till
- No tillage passes
- Residue minimally disturbed
- Maximize protection against erosion and crusting

Reduced Tillage
- Zone tillage (single pass)
- Strip tillage
- Permanent beds
- Plastic mulch cover
- Reduced freq. of plow till
- …… and so on
Soil Health: One size does not fit all!

1. Evaluate your present system
2. Identify the problem areas
3. Quantify the problem if possible
4. Evaluate your resources/conditions
5. Try out a new system in small area
6. Fine-tune your system
7. Scale up after fine-tuning
Thanks!
Effect of different systems on soil quality

Low input system

No inputs (NI) = No fertilizers or herbicides. The only inputs are seed and tillage.

Conventional system

High input (HI) = Broadcast fertilizer and herbicides. Moldboard plowed most years.

No-till system

Reduced input (RI) = Reduced rates of banded fertilizer and herbicides. Reduced tillage, with no-till in most years.

Organic system

Organic input (OI) = No chemical fertilizers or herbicides. Aged manure is applied. Weeds are controlled through delayed planting and cultivation.

- - - - 2-yr rotation = corn-soybean
- 4-yr rotation = corn-soybean-oat/alfalfa-alfalfa

Deborah Allan at the University of Minnesota
Effect of different systems on soil quality

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Conventional Tillage

Reduced input (RI) = Reduced rates of banded fertilizer and herbicides. Reduced tillage, with no-till in most years.

No-Till

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