Building Soil Health: Why it Matters

David Lamm
National Soil Health & Sustainability Team, Leader
What are soils made of?

- Chemical
- Physical
- Biological
- OM
Ideal Soil Composition

- 25% Water
- 25% Air
- 5% Organic Matter
- 45% Inorganic (mineral materials)

Pore space 50%
Solids 50%
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
• 90% of soil functions mediated by microbes
<table>
<thead>
<tr>
<th>Organisms</th>
<th>Standing crop biomass lbs./ac.</th>
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<tr>
<td><strong>Above ground</strong></td>
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<tr>
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<tr>
<td>1200 Beef cow ²</td>
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<tr>
<td>Pasture³</td>
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<tr>
<td><strong>Below ground</strong></td>
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<td>Other fauna</td>
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SOIL IS HABITAT

Food
Water
Shelter

Pore Space
The Soil Food Web
Is very complex

Plants
Shoots and roots

Organic Matter
Waste, residue and metabolites from plants, animals and microbes.

Fungi
Mycorrhizal fungi
Saprophytic fungi

Nematodes
Root-feeders

Arthropods
Shredders
Predators

Protozoa
Amoebae, flagellates, and ciliates

Bacteria

Fourth trophic level:
Higher level predators

Third trophic level:
Shredders
Predators
Grazers

Second trophic level:
Decomposers
Mutualists
Pathogens, parasites
Root-feeders

First trophic level:
Photosynthesizers

Fifth and higher trophic levels:
Higher level predators

Animals

Arthropods
Predators

Birds
Nature moves towards a more complex system, more diverse, more productive...Disturbance destroys complexity...Nature starts up again

Dr. David Perry
Diversity of Root Architecture and Depths

Don et.al., 2008 Max Planck Inst. Jena
The Soil Food Web Drives Nutrient Cycling

- Plants: Shoots and roots
- Organic Matter: Waste, residue and metabolites from plants, animals and microbes
- Fungi: Mycorrhizal fungi, Saprophytic fungi
- Bacteria
- Protozoa: Amoebae, flagellates, and ciliates
- Nematodes: Root-feeders, Shredders, Predators
- Arthropods: Shredders, Predators
- Birds
- Animals

First trophic level: Photosynthesizers
Second trophic level: Decomposers, Mutualists, Pathogens, parasites, Root-feeders
Third trophic level: Shredders, Predators, Grazers
Fourth trophic level: Higher level predators
Fifth and higher trophic levels: Higher level predators

Dr. Nardi
Mineralization and Immobilization

Organisms consume other organisms and excrete inorganic wastes.

Organic nutrients are stored in soil organisms and organic matter.

Inorganic nutrients are usable by plants, and are mobile in soil.

Organisms take up and retain nutrients as they grow.
The Soil Food Web
Controls Non-Beneficial Organisms

- **Plants**
  - Shoots and roots

- **Organic Matter**
  - Waste, residue and metabolites from plants, animals and microbes.

- **Fungi**
  - Mycorrhizal fungi
  - Saprophytic fungi

- **Nematodes**
  - Root-feeders
  - Shredders
  - Predators
  - Fungal- and bacterial-feeders

- **Arthropods**
  - Predators

- **Protozoa**
  - Amoebae, flagellates, and ciliates

- **Animals**

**Trophic Levels**

- **First trophic level:** Photosynthesizers
- **Second trophic level:**
  - Decomposers
  - Mutualists
  - Pathogens, parasites
  - Root-feeders
- **Third trophic level:**
  - Shredders
  - Predators
  - Grazers
- **Fourth trophic level:**
  - Higher level predators
- **Fifth and higher trophic levels:**
  - Higher level predators
Controlling Pest Requires Every Trophic Level

- Must be present
- Must be able to function

IPM

- Prevention
- Avoidance
- Monitoring
- Suppression
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
Soil Health Principle 1
Manage More by Disturbing Soil Less

• Agricultural Disturbance Destroys Dynamic Soil Properties
• Destroy “Habitat” for Soil Organisms
• Creates a “Hostile” Environment
• Three Types of Disturbance
  – Physical (tillage)
  – Chemical (Fertilizer)
  – Biological (overgrazing)
What is Tillage?

The physical manipulation of the soil for the purpose of:

• Management of previous crop residue
• Control of competing vegetation (weeds)
• Incorporation of amendments (fertilizer/manure)
• Preparation of a soil for planting equipment
• Recreation for folks who don’t fish or golf
What Tillage does to the Soil

• Destroys aggregates
• Exposes organic matter to decomposition
• Compacts the soil
• Damages soil fungi
• Reduces habitat for the Soil Food Web
• Disrupts soil pore continuity
• Increases salinity at the soil surface
• Plants weed seeds
Management Changes Soil Properties & Capacity of Soil to Function

Forest
SOM = 4.3 %

CT 17 yr- Soybean monoculture
SOM = 1.6 %

62.8% loss of SOM after 17 yr intensive tillage
Human nature drives us to tillage!

- We enjoy power!
- Feel in control!
- We can see what we accomplished!
Biological Disturbance

– No crop rotation diversity
  • Growing single species or few crops in rotation
  • Lack of diversity limits diversity of plant root exudates
  • Hampers the development of a diverse soil biota

– Overgrazing
  • Plants are exposed to intensive grazing for extended periods of time, without sufficient recovery periods
Biological Disturbance of Overgrazing

1. Reduced root mass
2. Increased weeds
3. Reduced soil fungi
4. Reduced water infiltration
5. Increased soil temperature
6. Diminished soil habitat
Alternative water sources & controlled access to stream but no control of grazing time on watershed
Chemical disturbances: over-application of pesticides, fertilizers, amendments & manures
Impact of Pesticides on Soil Health

- Impacts non-target organisms
  - not well understood
  - Fungicide takes out mycorrhizal fungi
- Pesticides simplify, not diversify
- May restrict crop rotation
- May restrict cover crop diversity
Impact of Fertilizer on Soil Health

- Short-circuits the rhizosphere & P cycle
- Depresses activity of natural N fixers
- Stimulates bacterial decomposition of SOM
- Excess N at risk for leaching or denitrification
- Increased soil salinity (Synthetic fertilizers are salts)
Impact of Manure on Soil Health

• Can add organic matter and carbon
• Build up of P to excessive levels
  – Greater than 100 ppm discourages plants from feeding mycorrhizal fungi
• Other issues
  – Heavy metals
  – Salts
  – Pathogens
  – Soil compaction from application/incorporation
Hard to believe that the same results can be achieved using simpler biological methods!!!
Healthy Soils are forgiving soils
Soil Health Principle 2

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
Nitrogen Types in Plant Exudates

Nitrate (blue)
Amides (Yellow)
Ureides (red)
Impact of Biodiversity

• Lack severely limits any cropping system
• A diverse and fully functioning system provides nutrients, energy and water
• Diversity above ground equals diversity below ground
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
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 6 to 8 weeks of growth is adequate to get some of the “rotation” effect benefits!
4. Will increase soil biological diversity “Diversity above = diversity below”
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
Mimic Native Range

- Diversity of Plants
- Diversity of Function
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

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Diversity and Microbial Community Biomass

![Graph showing the relationship between the number of species and microbial biomass.](image-url)
Diversity and Microbial Community Respiration

![Graph showing the relationship between the number of species and microbial respiration (µmol CO₂·g⁻¹·d⁻¹).](image-url)

- **X-axis**: # of species
- **Y-axis**: Microbial respiration (µmol CO₂·g⁻¹·d⁻¹)

The graph demonstrates an increase in microbial respiration with an increase in the number of species.
Cover Crop Characteristics
Mixture of cereal rye, hairy vetch, and field peas as a winter cover crop

Mixture of cereal rye, hairy vetch and crimson clover
Soil Health Principle 3
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 redeposit nutrients
• Increases OM
Root Mass in Top 4" of Soil

- Rye & Hairy Vetch Cover Crop
- Corn Grain
- Soybean 7" rows

Lbs./ac.

Graph showing root mass in top 4" of soil for different crops over a year.
Cover Crops Retain N in the Soil

Figure 3. Effect of a cereal rye cover crop on soil nitrate concentrations (ppm) in broccoli plots fertilized the previous spring with 250 pounds N/acre. Samples were taken April 15, 1992. (Data from Hemphill and Hart, 1993.)

Using winter cover crops to reduce nitrate contamination of ground water requires the establishment of the crop early enough in the fall to have adequate growth during the fall and winter rains. Relay interplanting of the cover crop into the standing cash crop during the summer has shown promise in getting a crop well established by winter. Selection of fast-growing cultivars is also important.

J. Luna, OSU, Corvallis
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
Cover crops for resource assimilation and dry matter production.
How to Keep a Living Root All Year Long

• Lengthen Rotation
  – Add Wheat

• Select Shorter Season Varieties
  – Choose 100 - 104 day
  – Only need 6 - 8 weeks to provide benefit

• Interseed into Growing Crops
  – Planting cover crop before harvesting of cash crop
Hairy vetch planted into corn July 17

Hairy vetch planted into bean June 29

Photos 29 Oct 2003

Hairy vetch good fall growth
Fall Biomass Data

• Lose 50% to 80% of fall growth potential with a 1 month planting delay

• Later planting defers growth potential to spring

• Rye is the least impacted by a later planting date

Dry Matter of Both Planting Dates Measured in November
Spring Biomass Data

Cover Crop Biomass in April/May 2010

- Rye and triticale containing mixtures were least impacted by a later planting date.
- Ryegrass containing mixtures were moderately impacted by a later planting date.
- Legumes with no spring growing companions were heavily impacted by a later planting date.
How are farmers getting it done?

Aerial Seeding
Penn State Cover Crop
InterSeeder & Applicator
• Seed cover crops into corn & beans
• Uses a Hagie STS 12 with a Gandy Orbit Air seed box.
• Covers 90 feet / 36 rows and the hopper holds 65 bu.

Highboy air seeders
“This is the last and greenest field I did. Still has a little time to go yet, but it should make some corn. Most other fields are brown with grain moisture, I'm guessing, in the low 20's. The ground is getting more light, so we'll see if that makes a difference.”
Broadcast while defoliating cotton

Seeded a multi-species cover crop mix
- Cereal rye
- Crimson clover
- Hairy Vetch
Corn Chopper --
cuts top out of mature corn
Soil Health Principle 4

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    
70 F  100% moisture is used for growth

J.J. McEntire, WUC, USDA SCS, Kernville TX, 3-58 4-R-12198. 1956
What happens to residue?

Diagram by Dr. Rafiq Islam
Soil Organic Matter
Nutrient Bank Account.

- 1.0% OM = 20,000 #
  - 10,000 # Carbon (5 ton) @ $4/ton = $20
  - 1,000 # Nitrogen @ $.50/# = $500
  - 100 # Phosphorous @ $.70/# = $70
  - 100# Potassium @ $.40/# = $40
  - 100 lbs of Sulfur @ $.50/# = $50
  - Total $680

- Mineralization Rate = 2-3% from Organic N to Inorganic N.

- Resulting in 20 to 30 lbs of useable N per acre.
Soil Organic Matter & Available Water Capacity

<table>
<thead>
<tr>
<th>Percent SOM</th>
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<th>Silt Loam</th>
<th>Silty Clay Loam</th>
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Inches of Water/One Foot of Soil
1 acre inch = 27,150 gallons of water

Berman Hudson
Journal Soil and Water Conservation 49(2) 189 194 189-
March April 1994 –
Summarized by:
Dr. Mark Liebig, ARS, Mandan, ND
Hal Weiser, Soil Scientist, NRCS, Bismarck, ND