Soil Health and Carbon Dynamics

Mahdi Al-Kaisi, Professor
Soil Management/Environment
Presentation Outlines

- Basic Concept of Soil Health
- Soil Heath Indictors
- Management Effects on Soil Health
- Soil Organic Matter and Soil Health
- Soil Organic Matter and Productivity
- Soil Services Nexus
Our Productive Land...

WE CAN CONSERVE AND IMPROVE IT WHILE USING IT

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SOIL CONSERVATION SERVICE
Relative mineral particle size in soil

Soil Organic Matter size covers the same range with some soluble.

- **Sand**: 2.0 – 0.05 mm
- **Silt**: 0.05 – 0.002 mm
- **Clay**: < 0.002 mm

The soil contains only a small amount of organic matter that plays a vital role in agriculture.

Soil Composition

- **organic matter**: 5%
- **soil minerals**: 45%
- **air**: 25%
- **water**: 25%

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What is Soil Health?

Soil health is the long-term vital functionality and capacity of soil biological, physical, and chemical soil properties as a living and complex system that will sustain plant and animal productivity, soil biodiversity, maintain or enhance water and air quality, and support human health and wildlife habitat.
Soil Health Means

- Improves soil organic matter
- Sustains productivity
- Enhances soil physical and hydraulic properties
- Builds soil biology
- Improves environment through ecological services
Soil Health Indicators and Factors

- **Indicators**
  - Aggregate Stability
  - Soil Structure
  - Soil porosity
  - Bulk Density
  - Water Infiltration
  - Water Holding Capacity
  - Soil Available Water

- **Inputs**
  - Root system
  - Cover crops
  - Crop Residue
  - Animal manure

- **Soil Physical Properties**

- **Soil Organic Matter**
  - Tillage
  - Crop rotation
  - Cover crops
  - Grass water ways
  - Perennials

- **Soil Chemical Properties**
  - Cation Exchange Capacity
  - Organic and Inorganic N
  - Organic and Inorganic P
  - Organic and Inorganic K
  - Soil pH

- **Soil Biological Properties**
  - Earthworms
  - Soil Microorganisms
  - Particulate Organic Matter
  - Soil Respiration
  - Soil Enzymes
Why We Use Soil Health Indicators

- Representative of soil function
- Sensitive to change in management
- Easily measured and reproducible
- Reliable
- Applicable to field conditions

(Doran and Parkin, 1994; Gregorich et al., 1994)
Soil Organic Matter Composition

Soil organic matter
1-6% of total soil mass

Mineral particles

Soil microbial biomass
3-9% of total SOM mass

Stable (humus)
70-90%

Fungi
50%

Bacteria & actinomycetes
30%

Yeast, algae, protozoa, nematodes
10%

Readily decomposable
7-21%

Fauna
10%

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Physical Indicators:

Soil Structure

The arrangement of primary soil particles into aggregates of a definite shape and size.

• Particles attached by a combination of clay surface effects, humus, bacterial secretions, iron, and aluminum oxides.

• Affects water movement, root growth, and aeration.
• Hyphae of arbuscular mycorrhizal fungi grow beyond nutrient depleted zones found around roots and root hairs.

• Hyphae form a frame for soil particles to collect into aggregates which are coated with *Glomalin*.

Kris Nichols, USDA-ARS
Northern Great Plains Research Lab
Why Soil Structure is Important?
The naturally occurring arrangement of soil particles into secondary units “aggregates” or peds can provide:

• Biophysical Strength
• Hydraulic Soil Properties
• Root development environment
• Biodiversity in Rhizosphere
• Balanced Soil Moisture and Aeration
• Nutrient Capacity
Residue Management Effects on Soil Structure

No-till with no residue removed

No-till with residue removed
Management Effects on Soil Structure

Structureless

Good Structure

Soil Compaction Layer
Which solution would you use?

The plow is one of the most ancient and most valuable of man’s inventions; but long before he existed the land was in fact regularly ploughed, and continues to be thus ploughed by earthworms. — CHARLES DARWIN, 1881
Tillage and Cropping Systems Effects on Soil Health Indicators

- Soil Organic Matter: Tillage accelerates OM loss
- Soil Compaction and Bulk Density: Tillage increases both.
- Water Infiltration: Tillage reduces Inf. and increases surface runoff
- Microbial Biomass: Intensive tillage mono-cropping system can reduce microbial biodiversity.
Tillage effects on total organic carbon % in the top 6 inches soil depth after 3 years of residue removal.
Aggregate Stability

North Central, Iowa
poorly-drained soil

Residue Removal (%)
0 50 100

Mean Weight Diameter (mm)
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8

Chisel plow
No-till

North Central, Iowa
poorly-drained soil

Side-dressed UAN (lbs N ac\(^{-1}\))
0 150 250

b b c a c c b a a
Example of Residue Management Effects on Bulk Density

- Ames, IA
- Lewis, IA

Baseline: 1.25
Baseline: 1.28

Residue Remaining (tons/acre)
2.7 1 0.1

Bulk Density (g/cm³)
1.0 1.1 1.2 1.3 1.4 1.5 1.6

CT
NT

Graph showing the effects of residue management on bulk density at Ames, IA and Lewis, IA.
Example of Tillage and Residue Management Effects on Water Infiltration Rate

![Bar Chart]

**Ames, IA**
- Residue Remaining (ton/acre): 2.7, 1, 0.1
- Steady Infiltration Rate (inches/min): CT, NT

**Lewis, IA**
- Residue Remaining (ton/acre): 2.7, 1, 0.1
- Steady Infiltration Rate (inches/min): CT, NT
Relationship Between Tillage Intensity, Bulk Density, and Water Infiltration

Infiltration or Bulk Density

Infiltration

Bulk Density

B.D = Weight of Soil/Total Soil Volume

Tillage Intensity
Water Recharge

- NT and ST increased water recharge by 50-70% over conventional tillage systems.

Cumulative water infiltration under five tillage systems.

NT=no-till; ST=strip-tillage; CP=chisel plow; DR=deep rip; MP=moldboard plow.
Relationship Between Aggregate Stability and Soil OM

(Al-Kaisi et al., 2014, SWCJ)
Relationship Between Soil Water Storage and Organic Matter

Soil organic carbon (Mg ha\(^{-1}\))

Moisture content (cm\(^3\) cm\(^{-3}\))

\[ y = 0.02x - 0.32 \]

\[ r = 0.70 \]

(Al-Kaisi et al., 2014, SWCJ)
Residue Management Effects on Soil Health

- Soil organic C input
- Soil surface structure
- Soil temperature and org C&N mineralization
- Sub soil water-recharge
- Soil erosion and nutrients loss
- Long-term potential yield reduction
20 years of similar tillage intensity and C inputs but contrasting types of organic inputs
Soil organic matter including humus & microbial biomass

**ATMOSPHERE**

CO₂

Photosynthesis

O₂

SOIL

Root respiration

CO₂

Plant uptake

O₂

Rapid release

Slow mineralization

Decomposition and exudation

Microbial respiration

CO₂

O₂

Soil organic matter including humus & microbial biomass

Modified from Rowell (1994)
How Land Use Affects Soil C Dynamics

- **Prairie**
  - Steady State: $\text{NPP} = R_h$
  - Carbon Accumulation: $\text{NPP} > R_h$

- **Conversion to cropland**
  - Carbon Loss: $\text{NPP} < R_h$

- **Adoption of conservation practices**
  - Potential Carbon Sequestration

**Definitions**
- $\text{NPP} = \text{Net Primary Production}$
- $R_h = \text{Carbon loss via microbial decomposers}$
Productivity and Soil Organic Matter

\[ y = 19.61 + 1.37x \]

\[ r = 0.74 \]

(Al-Kaisi et al., 2014, J. Acad. Sci.)
10-year County Average Corn Yield vs. County Average Soil Carbon Index in Iowa

\[ y = 124.9 + 1.25x \]
\[ r = 0.56 \]
Soil Ecosystem Services

- **Provisioning Services**: The products obtained from ecosystem
  - food
  - fibre
  - fresh water
  - genetic resources

- **Regulating Services**: The benefits obtained from the regulations ecosystem processes
  - climate regulation
  - hazard regulation
  - noise regulation
  - pollination
  - disease and pest regulation
  - regulation of water, air and soil quality

- **Supporting Services**: Ecosystem services that are necessary for the production of all other ecosystem services
  - soil formation
  - nutrient cycling
  - water cycling
  - primary production

- **Cultural Services**: The non-material benefits people obtain from ecosystems
  - spiritual or religious enrichment
  - cultural heritage
  - recreation and tourism
  - aesthetic experience

(MEA, 2005)
Soil Health Paradigm

- Soil Biodiversity
- Nutrient Reserves
- Crop Yield
- Plant Biomass
- Root growth
- Soil Structure
- Water Holding Capacity
- Soil Organic Matter

Lal, Kimble, and Follett 1997
How to Improve Soil Health

- Traffic management/control
- Inclusion of forage legumes, small grain, and cover crops in the crop rotation
- Increase in organic matter/use of animal manure
- Keep residue on soil surface
- Adoption of NT and reduced tillage along with other conservation practices
- Integration of perennials within row crops
- Control soil erosion