(1) "Soil Health Principles" (used to develop a Soil Health Management System (SHMS):
- Maximize Biodiversity (diverse crop rotation & cover crops)
- Provide Continuous Living Root (roots thru out the year)
- Maximize Soil Cover (living plants, crop residues, mulch)
- Minimize Disturbance (i.e. biological, physical & chemical disturbances are low (e.g. has low inputs))
- Livestock Integration (were applicable; use adaptive grazing (rgt.)). Keep the soil armored/covered at all times.

Resilience comes from Diversity (conduit for energy & nutrients)

Soil Health is Understanding How the Soil is Designed to Function and Managing it Accordingly

Rudy Garcia
Regional Soil Health Specialist (AZ, CO, NM, UT)
Natural Resources Conservation Service
(1) “Soil Health Principles” (used to develop a Soil Health Management System (SHMS)):
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**Road Map to Soil Health**

Field Soil Health Assessments/Observations of SHMS:

- Evaluate crop condition
- Dig a small soil pit & assess/evaluate

**“Biological Spheres” (Record assessments & observations)**

(1) **All Biological Spheres are present & well-defined…**

- (dig a small soil pit): Topsoil is clearly defined (i.e. no mixing w/ subsoil) and has dark soil color. Soil aroma has an earthy & sweet smell. These spheres provide an ideal Soil Food Web environment, which facilitate optimum “Carbon,” “Nutrient” & “Water” cycles & increases filtering/buffering capacity:
  
  **(I) Rhizosphere (roots):** Healthy roots & deep rooted (i.e. increased water-holding capacity & has higher drought tolerance). Legumes have active nodules. Easy to observe rhizosheaths.
  
  **(II) Aggregates:** Water-stable surface macro-aggregates, which provide ideal soil structure (crumbly/granular & cottage cheese appearance). There is no surface or subsurface compaction (ideal bulk density/porous soil). Saline & sodic conditions are easier to manage.
  
  **(III) Pores:** Large macro-pores are present (i.e., due to formation of macro-aggregates & earthworm pores, roots). Has high infiltration rates & clear runoff w/ heavy rains.
  
  **(IV) Detritusphere (surface residues):** Shredded & signs of life, with the majority of the surface covered. Has lower soil temperature & reduced evaporation, which results in higher water-use efficiency.
  
  **(V) Drilosphere (earthworms):** Bio-pores, castings & mittens are present. Soil is well-aerated & has good soil tilth.

(2) **Soil Health Management System** (Must be “site-specific”): e.g. crop rotation, cover crops, no-till, minimum-till (vegetables), irrigation system, IWM, salinity mgt., nutrient mgt., IPM, adaptive grazing mgt. & other (composting, mulching, pollinator habitat)

(3) **Increased Production of Soil Organic Matter (SOM):** i.e., Quantity & Quality of Crop Residues & Roots & production of diverse Root Exudates (e.g., increased Soluble Organic Carbon content).

- Increase in diverse Soil Food Web (SFW) with optimal Fungal:Bacterial ratio; this results in sustained biological activity (CO2 Respiration) & nutrient cycling.

(4) **Crop Condition: “vigorous” & “uniform” growth (high yielding). Pollinators & beneficial arthropods are abundant.**

(5) **Healthy Soil = Healthy Plants**

(6) **TESTS to consider when Monitoring your SHMS:**

- (i.e., What do you need to KNOW about your “SHMS Performance” & where it needs Improvement): (1) Brix Reading, (2) Haney, (3) Soil Fertility, (4) Cornell Soil Health Assessment, (5) Earthfort (SFW), (6) PLFA, (7) B-Glucosidase, (8) Irrigation Water Quality, (9) Nitrate test strips, (10) Other; e.g., Tissue, Compost, Manure, Soil Biology Assays, etc.
Basic Field GUIDE to Assess Soil Health

Are all Biological Spheres present & well-defined:

1. **Rhizosphere**
   - Root depth (in.)
   - Root health/biomass (visual)
   - Soil Temperature (0-2”)

2. **Aggregatusphere**
   - Soil structure (e.g., granular)
   - Slake test at 0-3” depth
   - Is soil crusting?
   - Aggregate Stability (colander & spray bottle)

3. **Porosphere**
   - Infiltration test (in./hr.)
   - Compaction (psi)
   - Root biopores (visual)

4. **Detritusphere**
   - % Surface residue cover
   - Signs of Residue decomposition
   - Surface Temperature

5. **Drilosphere**
   - Earthworms (#/ft.³) & castings

Soil Texture/Soil Series:
- Soil Structure, Bulk Density, Water-Holding Capacity (in./ft.), Soil Stratification, Depth to Water Table (ft.), CEC/Base Saturation/ESP, Soil Color/Soil Aroma, OTHER: % Carbonates, Salinity, etc.

IRRIGATION:
- (1) Irrigation System (drip, sprinkler, furrow, etc.);
- (2) Available Irrigation (cfs/gpm);
- (3) Irrigation Water Quality (ECiw/SAR);
- (4) IWM/Scheduling (Feel & Appearance method; Tensiometer, etc.);
- (5) Consumptive Use (in./yr.);
- (6) OTHER: are fields leveled, etc.

Soil Health Mgt. System (SHMS) benefits:
- (Living roots & the SFW restore soil function):
  - Increases Soil Organic Matter (i.e. quantity & quality)
  - Topsoil is clearly defined (no mixing w/ subsoil)
  - All Biological Spheres are present & well-defined
  - Carbon/Nutrient/Water cycles are optimized
  - Biological, Physical & Chemical disturbances are low

SHMS benefits:
- Higher Infiltration Rate
- Reduced Compaction
- Lower Soil Temperature
- Lower Evaporation
- Increased Water-Use Efficiency
- Increased Drought Tolerance
- High Filtering & Buffering Capacity
- Easier to manage salinity/sodicity
- Lower Inputs
- Increase in Pollinators
- Increase in diverse SFW
- Water & Wind Erosion is none/negligible

Soil Solution
- pH
- Salinity (ECss)

Mineralization – Immobilization
- C:N Ratio
- Soluble Nutrients (e.g., OC, ON, OP, NH₄⁺, NO₃⁻, other: K⁺, Ca₂⁺, etc.)
- Fungal:Bacterial Ratio

Dissolved Oxygen (O₂) & Carbon Dioxide (CO₂)

Bacteria
(Other: protozoa, nematodes, etc.)

Mycorrhizal hyphae

“Biological Activity” (CO₂ Respiration) is influenced by:
- Moisture & Temperature

Additional Tests (as needed):
- (1) Brix Reading, (2) Soil Fertility, (3) Tissue/Petiole, (4) Haney Test,
- (5) Earthfort (SFW), (6) PLFA, (7) CSHA, (8) B-Glucosidase, (9) Soil Biology Assays (diseases), (10) OTHER: e.g., Nitrate Strips, Compost, etc.

(A diverse Soil Food Web (SFW) recycles nutrients efficiently)

rudy.garcia.2017
The BIG Picture

- The most sustainable production system in the long-term is one that *mimics* nature as much as possible.
- If one goes against nature, eventually failure (ecological and/or financial) will be the end result.

**The Four Ecosystem Processes**

1. **Energy flow** - Maximize the flow of solar energy through plants and soil.

2. **Water cycle** - Maximize capture and cycling of water through plants and soil. Reduce export and import.

3. **Mineral cycle** - Maximize cycling of nutrients through plants and soil.

4. **Community dynamics** - High ecosystem biodiversity with more complex mixtures and combinations of desirable plant species leads to increased stability and productivity.
Soil Health Principles

- Minimize Disturbance
- Maximize Soil Cover
- Maximize Biodiversity
- Provide Continuous Living Roots
- Livestock Integration

Soil Health

- 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% is mitigated by soil microbial activity
How do these Ecosystem flourish without human inputs?

Soil Health Principles mimic nature

Ecology: the study of relationships between people, animals, and plants, and their environment (Interconnectedness)

Natural Systems:
- harvest the maximum amount of sunlight
- leak very few nutrients including CO₂
- have diversity
- tend not to export nutrients
- make maximum use of water and nutrients by having highly developed porosity and VAM webs
(2) “Soil Health Management System”
(Must be “site-specific”)

e.g. crop rotation, cover crops, no-till,
minimum-till (for vegetables), irrigation system(s), IWM, salinity
mgt., nutrient mgt., IPM, adaptive grazing mgt. & other (e.g.
composting, mulching, pollinator habitat, etc.)

North Valley Organics
(Minor Morgan; Albuquerque, NM)
(3) Production of higher **Soil Organic Matter** (i.e., **Quantity** & **Quality** of crop residues & roots) & production of diverse **Root Exudates** (e.g., increased **Soluble Organic Carbon** content).

- **Diverse Soil Food Web** with optimal Fungal:Bacterial ratio; this results in sustained/optimal Biological activity (e.g., CO$_2$ Respiration & nutrient cycling).

<table>
<thead>
<tr>
<th>Soil Organic Matter Fraction</th>
<th>Particle Size (mm)</th>
<th>Turnover Time (years)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>plant residues</td>
<td>≥ 2.0</td>
<td>&lt; 5</td>
<td>recognizable plant shoots and roots</td>
</tr>
<tr>
<td>particulate organic matter</td>
<td>0.06 – 2.0</td>
<td>&lt; 100</td>
<td>partially decomposed plant material, hyphae, seeds, etc</td>
</tr>
<tr>
<td>soil microbial biomass</td>
<td>variable</td>
<td>&lt; 3</td>
<td>living pool of soil organic matter, particularly bacteria and fungi</td>
</tr>
<tr>
<td>humus</td>
<td>≤ 0.0053</td>
<td>&lt; 100 – 5000</td>
<td>ultimate stage of decomposition, dominated by stable compounds</td>
</tr>
</tbody>
</table>
Soil Health Mgt. System (SHMS):
1. Crop Rotations
2. Cover Crops
3. OTHER: e.g., Nutrient Mgt., IPM, IWM, Irrigation Sys., etc.
4. No-Till & Reduced-Till for vegetables
5. Grazing Mgt. (as applicable)

Soil Health Planning Principles:
(1) Maximize Biodiversity
(2) Provide Continuous Living Roots
(3) Maximize Soil Cover
(4) Minimize Disturbance

*Integrate Grazing where applicable

"How to FIX Poor Soil Health"

- Maximize Biodiversity
- Provide Continuous Living Roots
- Maximize Soil Cover
- Minimize Disturbance

*Integrate Grazing where applicable

Sena, NM

"Optimal Nutrient Cycling"
Starting Point: 
Soil Health Planning Principles

1) Maximize Biodiversity
2) Provide Continues Living Root
3) Maximize Soil Cover (Plants & Crop Residues)
4) Minimize Disturbance (i.e., Biological, Physical & Chemical disturbances)
* Livestock Integration where applicable

SOIL CARBON is the key driver for the nutritional status of plants – and therefore the mineral density in animals and people

SOIL CARBON is the key driver for soil moisture holding capacity (frequently the most limiting factor for production)

Dr. Christine Jones
Cover Crops capture as much *free* solar energy as possible

- Every plant has a solar panel that is far less expensive than an artificial solar panel.
- The more natural solar panels there are per unit area, the more efficient that land is at capturing free energy.
- Bare ground doesn’t capture any energy.
Soil biological processes are responsible for supplying approximately 75% of the plant available nitrogen and 65% of the available phosphorus in the soil. Like all organisms, those inhabiting your soil need food and a favorable environment. Adequate organic matter content, ample aeration, moderate moisture, neutral pH, and warm temperatures all favor increased microbial activity.

Healthy Soil have Optimized Nutrient Cycling (Soil has a Diverse Soil Food Web)
**Ecosystem Engineer: Plant Roots**

What do they do?

- Capture solar energy
- Absorb water and nutrients
- Anchors the plant
- Roots release chemicals, nutrients, and carbon sources to stimulate and attract microbes
- Create biopores as roots die and are decomposed
- Involved in aggregation
- **Fuels soil organic matter building**

Maximize Biodiversity & Maximize Living Roots

- Break disease/pest cycles
- Stimulate/change belowground diversity
- Increase soil organic matter
- Increase nutrient cycling
- Enhance plant growth
- Increase predator & pollinator populations

Diverse roots is why you have a diverse Soil Food Web.

Nature and amounts of exudates are dependent on plant species, plant age, inorganic nutrients, soil and air temperature, light intensity, moisture content, $O_2/CO_2$ levels, transpiration rate, plant health and soil health.

Greater populations of microorganisms exist near the roots; they decrease with distance and depth of the root system.

Root Exudates: A major Food Source that feeds the complex Soil Food Web.

**Amino Acids (AA):** Basic compounds of living cells in plants and microorganisms.

**Organic Acids (OA):** They increase available insoluble nutrients, metals, mobilization & transport of minerals.

**Carbohydrates/sugars (CS):** Is food for microbes, stimulate their activity and improve plant resistance to diseases and pests.

**Nucleic Acid Derivatives (NAD):** Large molecules that carry genetic information (DNA & RNA).

**Growth factors (GF):** Known as phytohormones; chemical messengers that regulate plant growth.

**Enzymes (EZ):** Multi-protein complexes that aid catalyzing reactions that might not otherwise occur.

**Water soluble vitamins (WSV):** Vary with plant species; aid in the nutrition of microorganisms.

**Other compounds (OC):** Assist in plant health; in some cases they may attract, repel, or inhibit microorganisms.

Clarence Chavez 5/2014
(modified from original by rudy garcia)
The percentage of N in the roots as nitrate (blue), amino acids (green), amides (yellow) and ureides (red). These compounds leak from the roots as exudates and are part of the plant’s signature to create a unique rhizosphere.

Exudation of chemical compounds

- Initially thought to be leakage of amino acids, organic acids, carbohydrates, sugars, vitamins, proteins etc.
- But now known to be definite and individual
  - Feed biology
  - Signal microbes
  - Request support – nutrients
  - Ward off predators and competition
  - Symbiotic relationships

Dr. John Pate, 1976, Australia
Healthy Soils have a Diverse Soil Food Web

5% of soil organic matter is living organisms.

Greatest Geological Force is "Life" itself!
Continuous Flow of C Drives System

Atmospheric CO₂ → Plant C → Microbial Biomass C → Dead microbes → SOM–C → “Active” organic matter C → Respiration CO₂

Active Organic Matter

- Active Fraction (5-25%):
  - Highly degradable OM (lasts days to years);
  - Serves as food source of microbes; partially decomposed plant and animal tissue, microbial cells, biological compounds

- Passive Fraction (75-95%):
  - Resistant to decomposition (lasts 100s to 1000s of years)
  - Important for WHC and CEC

Image courtesy of Dr. Chenhui Li

Types of compounds in plant residues
- Fats and waxes: 2%
- Sugars & starches: 5%
- Cellulose: 45%
- Hemicellulose: 18%
- Lignin: 20%
- Polyphenols: 2%
- Protein: 8%

Composed of:
- Cellulose
- Chitin
- Proteins
- Carbohydrates
- Lipids
- Nucleic Acids
- Salts

“The soil microbial biomass is the eye of the needle, through which all organic materials must pass.” (Jenkinson, 1977)
Healthy Soil Recycles Nutrients and builds SOM

Additional N losses:
- runoff & erosion
- ammonia
- volatilization
- free-living N-fixing soil bacteria

Compost
Manure
Fungal Mycelia
Crop Residues

Rudy Garcia 2012

Mineralization: the conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Glomalin & Root Exudates are consumed by bacteria that live in the rhizosphere. Protozoa, nematodes & other soil organisms consume bacteria and release ammonium N. These organisms are prey for other SFW predators. The entire process results in mineralization.

Ref. The Nature and Properties of Soils, 14th Edition revised (Chapters 11, 12 & 13)
• All organisms that the plant requires are present and functioning
• Nutrients in the soil are in the proper form for plant uptake
• Correct ratio of fungi to bacteria is present

Most people are familiar with the above-ground food web: Plants are eaten by herbivores are eaten by carnivores, and so on. But most plant matter is not eaten by herbivores; it is decomposed by the underground food web. All plants depend on the soil food web for their nutrition.

File name: A-3 (145KB). (Also fw.jpg 574K, and fwb.jpg at 422K) Image courtesy of the USDA-NRCS.

Soil Foodweb Inc. 2009
Almost Every Element is Cycled by Microbes on this Planet

https://sciencenotes.org/printable-periodic-table/
Soil organic matter (SOM) is <6% of soil by weight but controls >90% of the function.