Soil Health Assessment and Management – Lessons from the Arid and Semiarid Southwest

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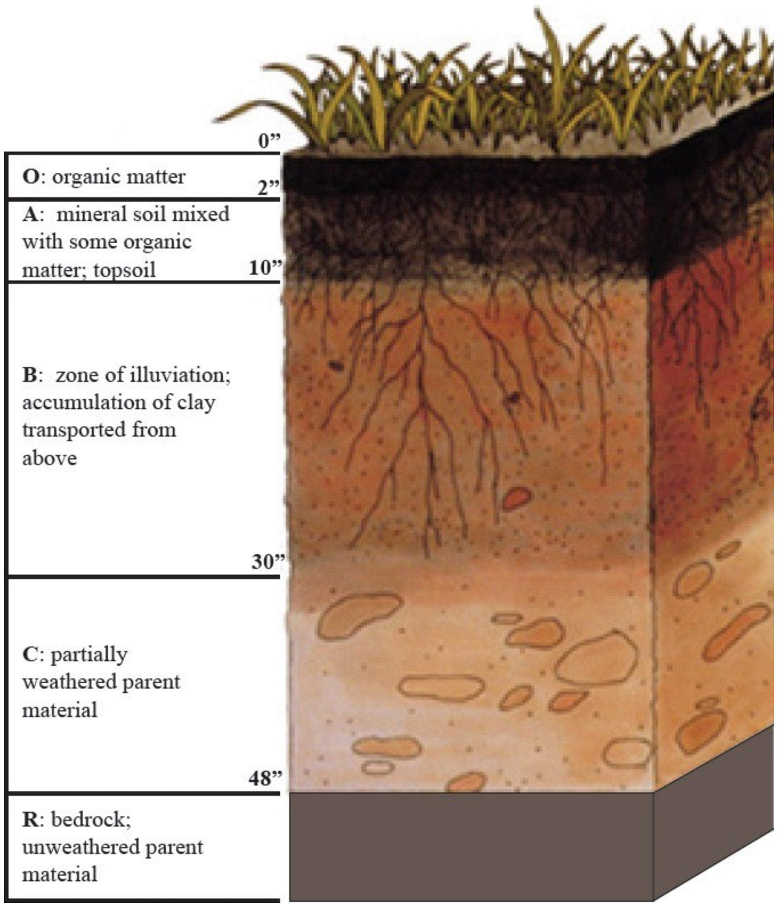
What is Soil Health?

- 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)

Aspects of Soil Health

- **Inherent soil quality**
  - Results from natural soil forming processes and factors
- **Dynamic soil quality**
  - Changes due to human use and management



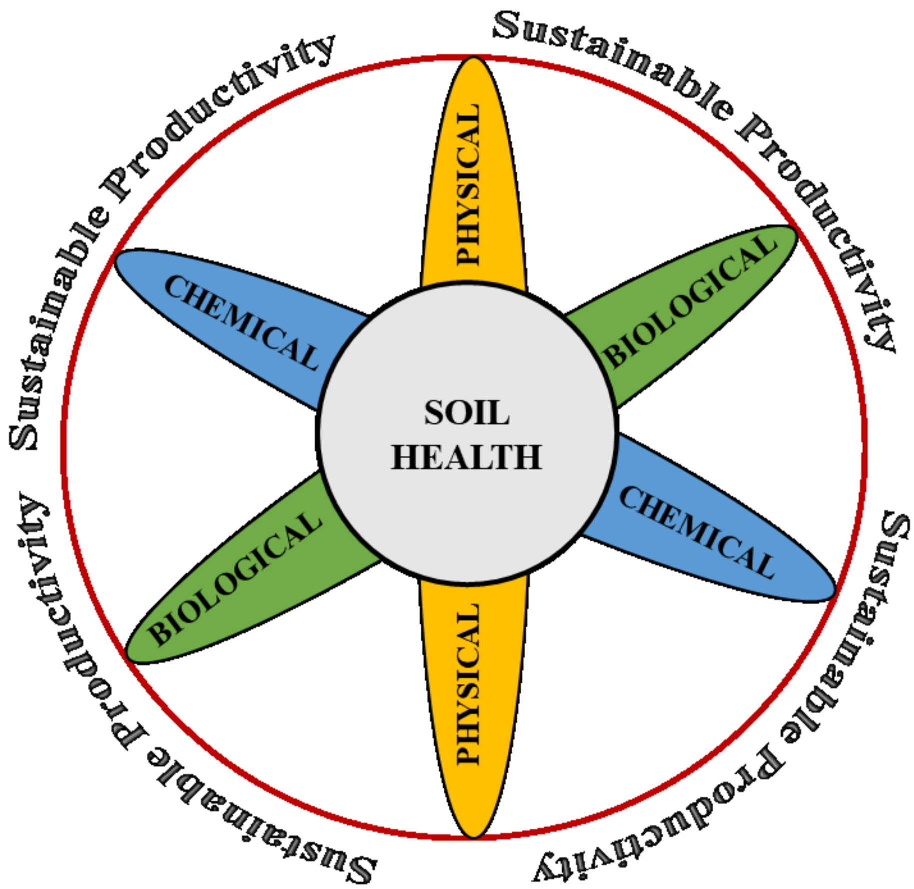
USDA-NRCS

How Healthy/Sick is a Soil?

If you can't measure it, you can't manage it

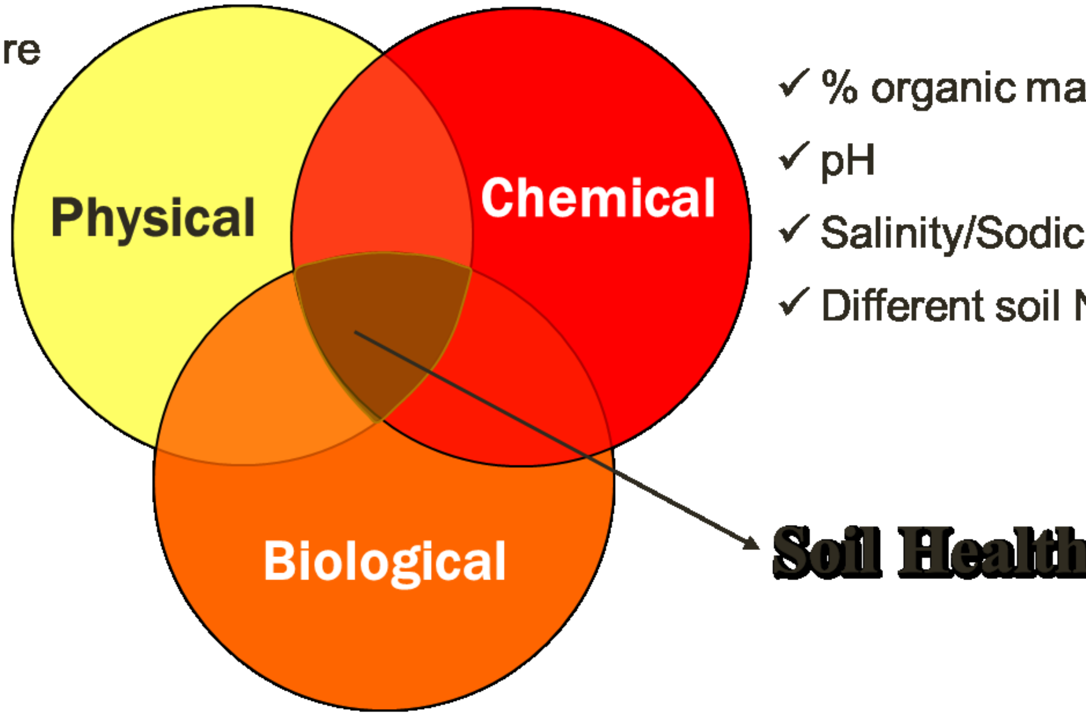
- How do we measure the problem?
- How do we manage soil health after detecting problems?

Soil Health Hub and Sustainable Productivity



Soil Health Processes and Functions

- ✓ Aggregation/Structure
- ✓ Water infiltration
- ✓ Water retention
- ✓ Soil Compaction
- ✓ Soil Erodibility



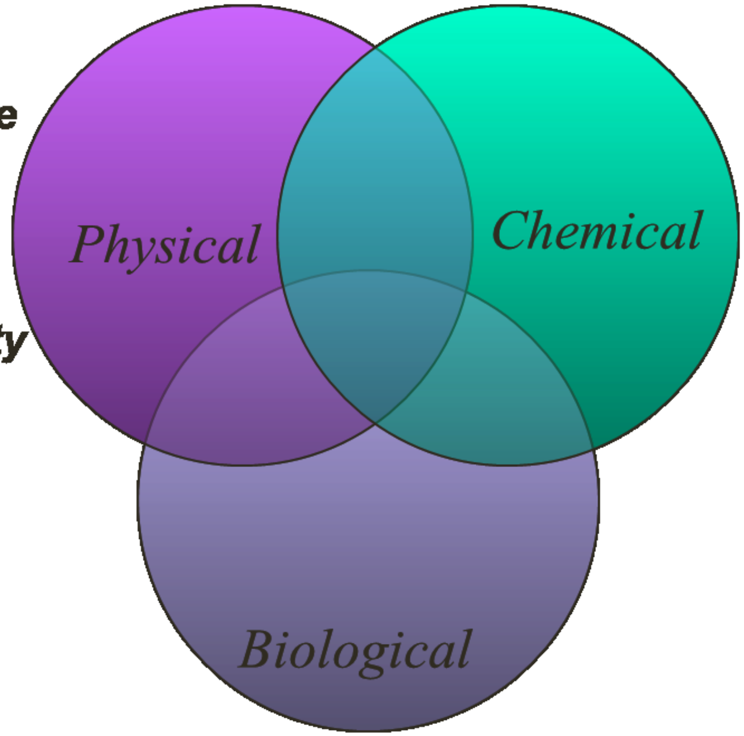
- ✓ % organic matter
- ✓ pH
- ✓ Salinity/Sodicity
- ✓ Different soil Nutrients

- ✓ Carbon sequestration capacity
- ✓ Microbial abundance and activity in the soil
- ✓ Nutrient cycling capacity

How do we capture the different processes by measurements called soil health indicators?

Soil Health Indicators

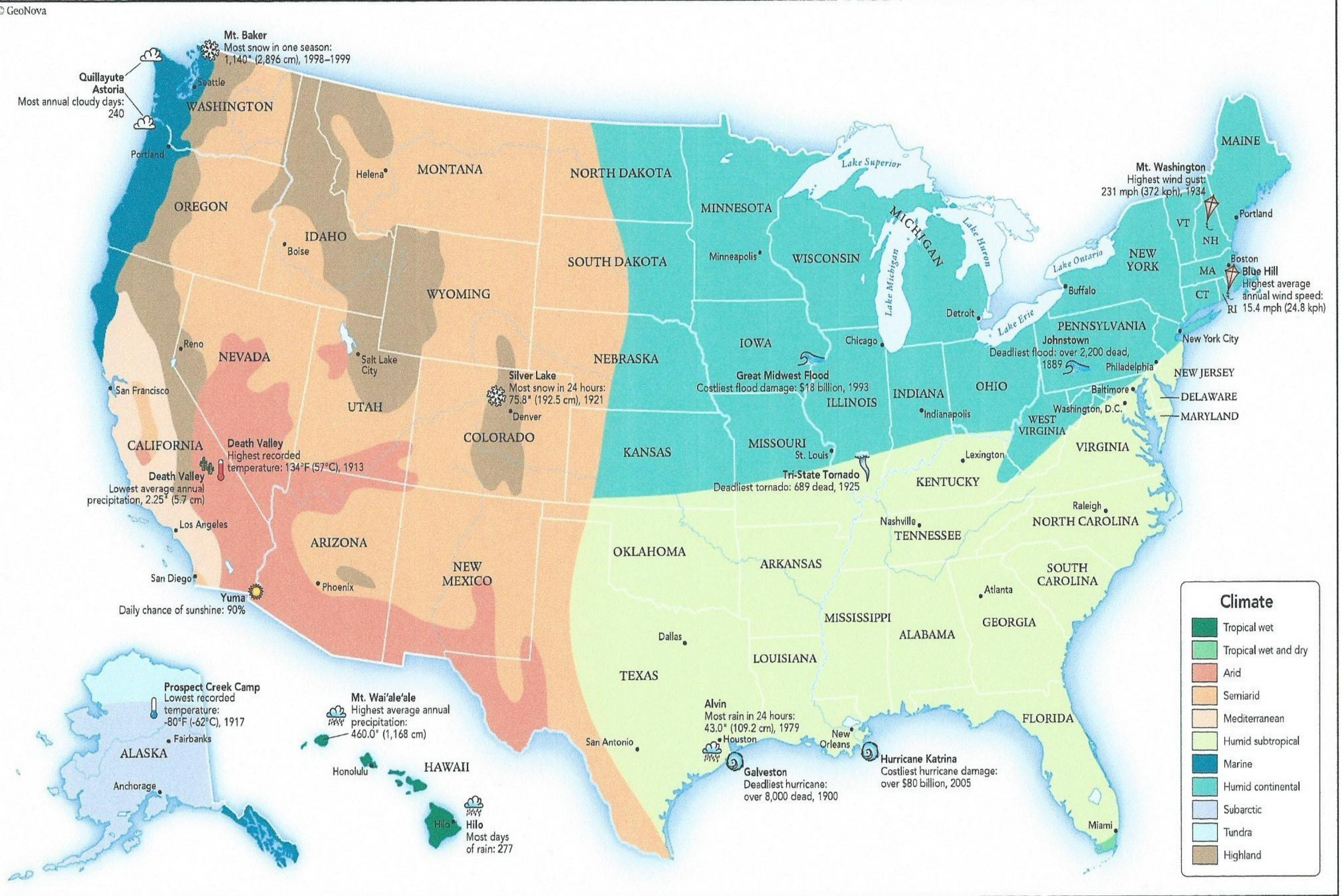
- ***Bulk density***
- ***Penetration resistance***
- ***Aggregate stability***
- ***Water infiltration rate***
- ***Water holding capacity***
- ***Soil Texture***



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

- ***Total Microbial Biomass***
- ***Mycorrhizae biomass***
- ***Diversity Index***
- ***N Mineralization***
- ***Respiration rate***
- ***Soil Organic Matter***
- ***Biologically Active Carbon***

Big Question: Which soil measurements best express soil health?


© GeoNova
Mt. Baker
Most snow in one season:
1,140" (2,896 cm), 1998–1999
Quillayute
Astoria
Most annual cloudy days:
240
Seattle
WASHINGTON
Portland
OREGON
Helena
MONTANA
IDAHO
Boise
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
MINNESOTA
Minneapolis
WISCONSIN
Lake Superior
MICHIGAN
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
MAINE
Mt. Washington
Highest wind gust:
231 mph (372 kph), 1934
Portland
VT
NH
NEW YORK
Boston
MA
Blue Hill
Highest average
annual wind speed:
15.4 mph (24.8 kph)
CT
RI
Buffalo
Detroit
PENNSYLVANIA
Johnstown
Deadliest flood: over 2,200 dead,
1889
Philadelphia
New York City
NEW JERSEY
DELAWARE
MARYLAND
Baltimore
Washington, D.C.
WEST VIRGINIA
VIRGINIA
Reno
NEVADA
Salt Lake City
San Francisco
UTAH
Silver Lake
Most snow in 24 hours:
75.8" (192.5 cm), 1921
Denver
COLORADO
NEBRASKA
IOWA
Chicago
Great Midwest Flood
Costliest flood damage: $18 billion, 1993
ILLINOIS
INDIANA
Indianapolis
OHIO
CALIFORNIA
Death Valley
Highest recorded
temperature: 134°F (57°C), 1913
Death Valley
Lowest average annual
precipitation, 2.25" (5.7 cm)
KANSAS
MISSOURI
St. Louis
Tri-State Tornado
Deadliest tornado: 689 dead, 1925
Lexington
KENTUCKY
Raleigh
NORTH CAROLINA
Nashville
TENNESSEE
Los Angeles
ARIZONA
OKLAHOMA
ARKANSAS
SOUTH CAROLINA
San Diego
Yuma
Daily chance of sunshine: 90%
Phoenix
NEW MEXICO
Atlanta
MISSISSIPPI
ALABAMA
GEORGIA
Dallas
LOUISIANA
TEXAS
Prospect Creek Camp
Lowest recorded
temperature:
-80°F (-62°C), 1917
Fairbanks
ALASKA
Anchorage
Mt. Wai'ale'ale
Highest average annual
precipitation:
460.0" (1,168 cm)
Honolulu
HAWAII
Hilo
Hilo
Most days
of rain: 277
San Antonio
Alvin
Most rain in 24 hours:
43.0" (109.2 cm), 1979
Houston
Galveston
Deadliest hurricane:
over 8,000 dead, 1900
New Orleans
Hurricane Katrina
Costliest hurricane damage:
over $80 billion, 2005
FLORIDA
Miami
Climate
Tropical wet
Tropical wet and dry
Arid
Semiarid
Mediterranean
Humid subtropical
Marine
Humid continental
Subarctic
Tundra
Highland

Potential Soil Health Indicators

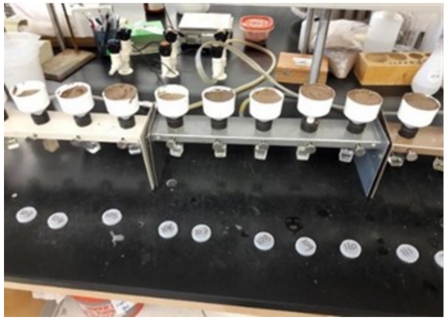
Physical – 10 Measurements

1. Mean Weight Diameter of Dry Aggregates (mm)
2. Dry Aggregates > 2mm (%)
3. Dry Aggregates < 0.25mm (%)
4. Sand (%)
5. Clay (%)
6. Silt (%)
7. Available Water Capacity (cm^3/cm^3)
8. Wet Aggregate Stability (%)
9. Bulk Density (Mg/m^3)
10. Penetration Resistance (psi)

Potential Soil Health Indicators

- **Chemical – 13 Measurements**

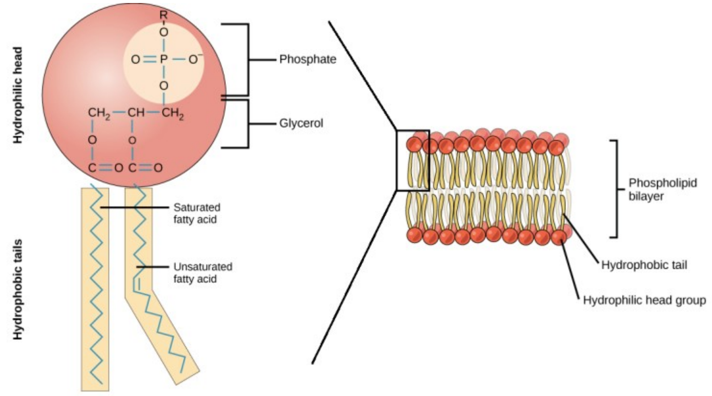
1. pH
2. EC (dS/m) (Salinity)
3. Sodium Adsorption Ratio
4. Nitrate Nitrogen (mg/Kg)
5. P (mg/Kg)
6. K (mg/Kg)
7. Ca
8. Mg
9. Na
10. Zn
11. Mn
12. Fe
13. Cu



Potential Soil Health Indicators

- **Biological – 17 Measurements**

1. Permanganate Oxidizable Carbon (Active carbon in the soil)
2. Soil Organic Matter
3. Total Microbial Biomass
4. Diversity Index
5. Total Bacteria Biomass
6. Actinomycetes Biomass
7. Gram (-) Biomass
8. Gram (+) Biomass
9. Rhizobia Biomass
10. Total Fungi Biomass
11. Arbuscular Mycorrhizal Biomass
12. Saprophytes Biomass
13. Protozoa Biomass
14. Undifferentiated Biomass
15. Fungi:Bacteria
16. Predator:Prey
17. Gram(+):Gram(-)



Phospholipid Fatty Acid (PLFA) Analysis

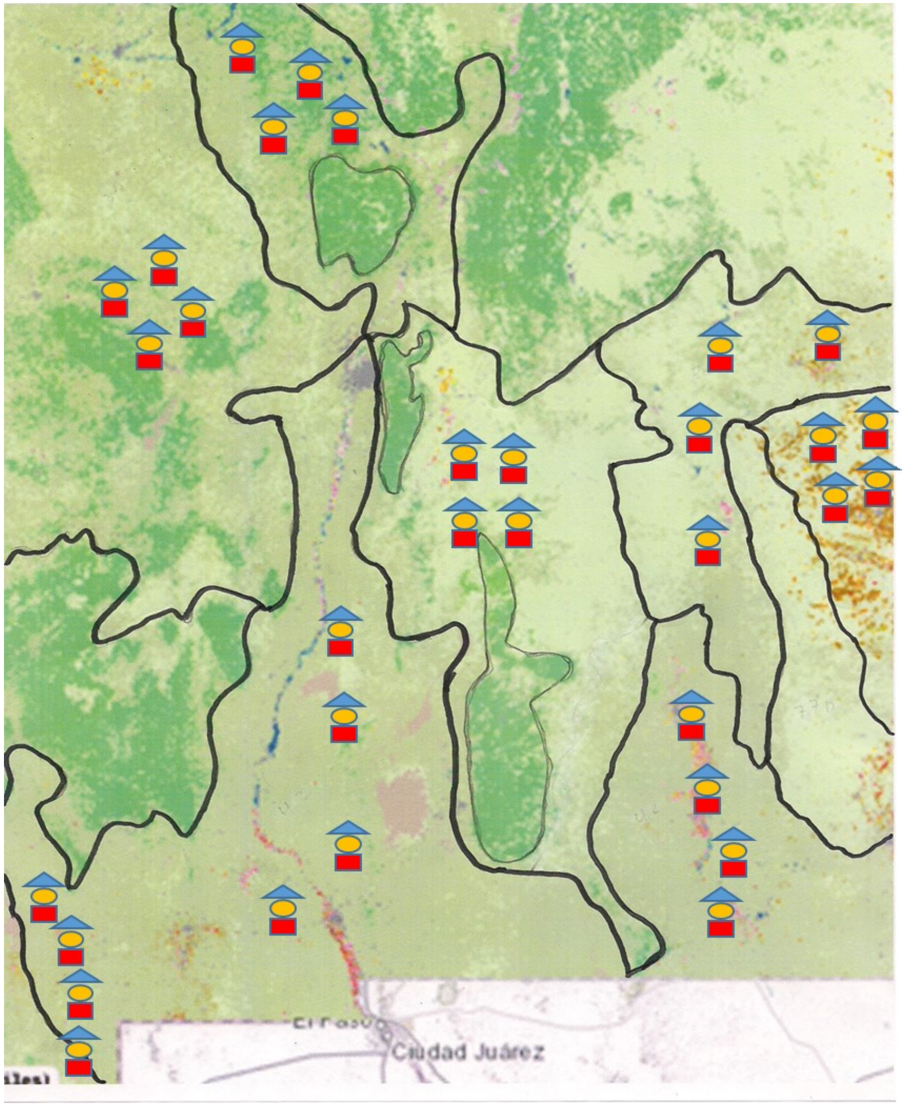
Approach to Soil Health Assessment

- **Research Farm Experiments**
  - Provide scientific basis from controlled trials to establish useful indicators
    - sensitivity of indicators

- **Commercial Farm Samples**
  - Provide real-world perspective under range of conditions
    - range of measurements

Soil Health Sampling in NM State

- Studied the research sites
  - Research sites with replicated treatments of management practices.
- Sampled commercial fields
  - Commercial fields with alternative management practices (crop type; tillage, rotation, etc.)



Management Practices and Soil Health Indicators

Treatments

- Clay- Permanent grass field with tall fescue (TFC) – 9 years
- Clay - Peach orchard with clover understory (POC) – 4 years
- Clay - An alfalfa field (ALF) – 9 years
- Clay - Conventionally tilled land with annual crops (CTC) – 9 years
- Sandy - A young cottonwood tree orchard (CWS) – 9 years
- Sandy - Conventionally tilled soil with annual crops (CTS) – 8 years

Site Description

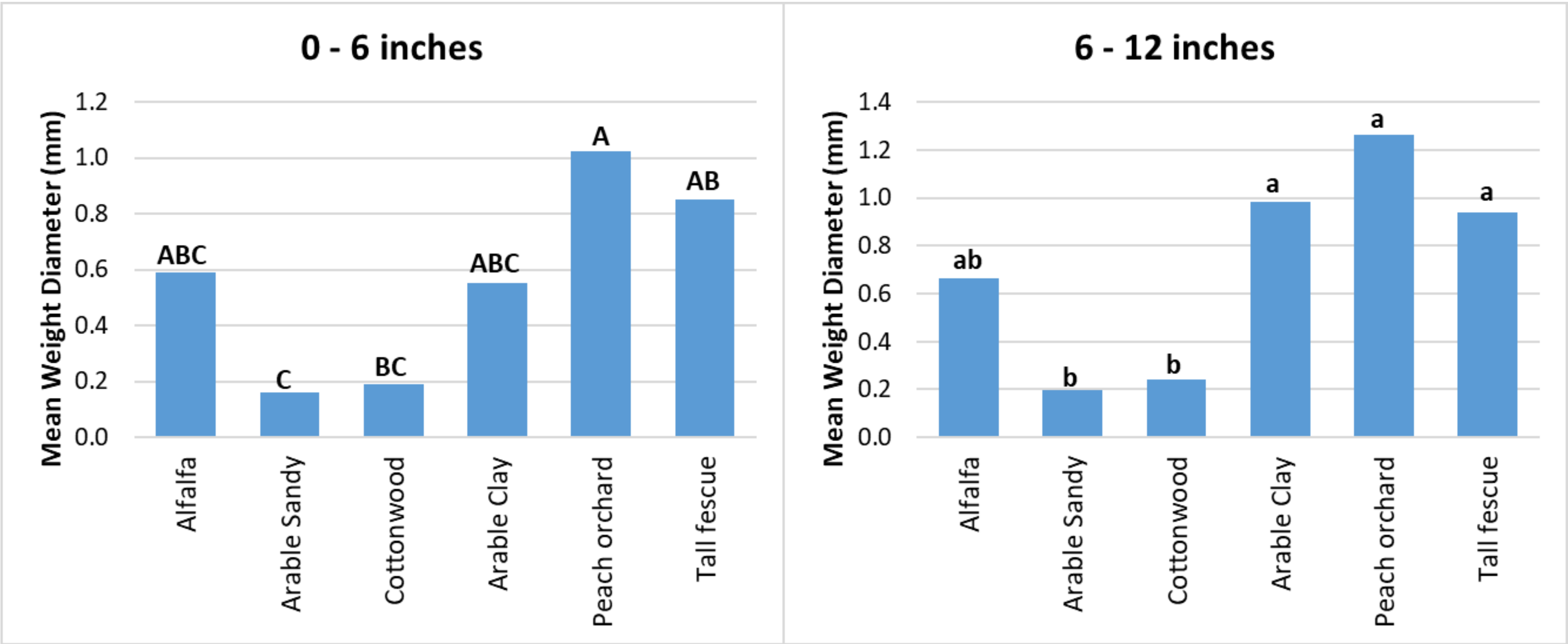
- NMSU Los Lunas Ag. Science Center
- [34°46'00.34"N, 106°45'31.95"W,]
- Elevation 1478.28 m (4850 ft)
- Mean annual high Temp. – 74°F
- Mean annual low Temp. - 38°F
- Annual Rainfall - 248 mm (9.75 in)
- Irrigated agriculture (well/Rio Grande water)

Mohammed Omer, Omololu J. Idowu, April L. Ulery, Dawn VanLeeuwen, Steven J. Guldan, Mark Marsalis and Rajan Ghimire (2020) Impacts of selected management practices on soil quality in an irrigated arid agroecosystem *Journal of Soil and Water Conservation* ***In Press***

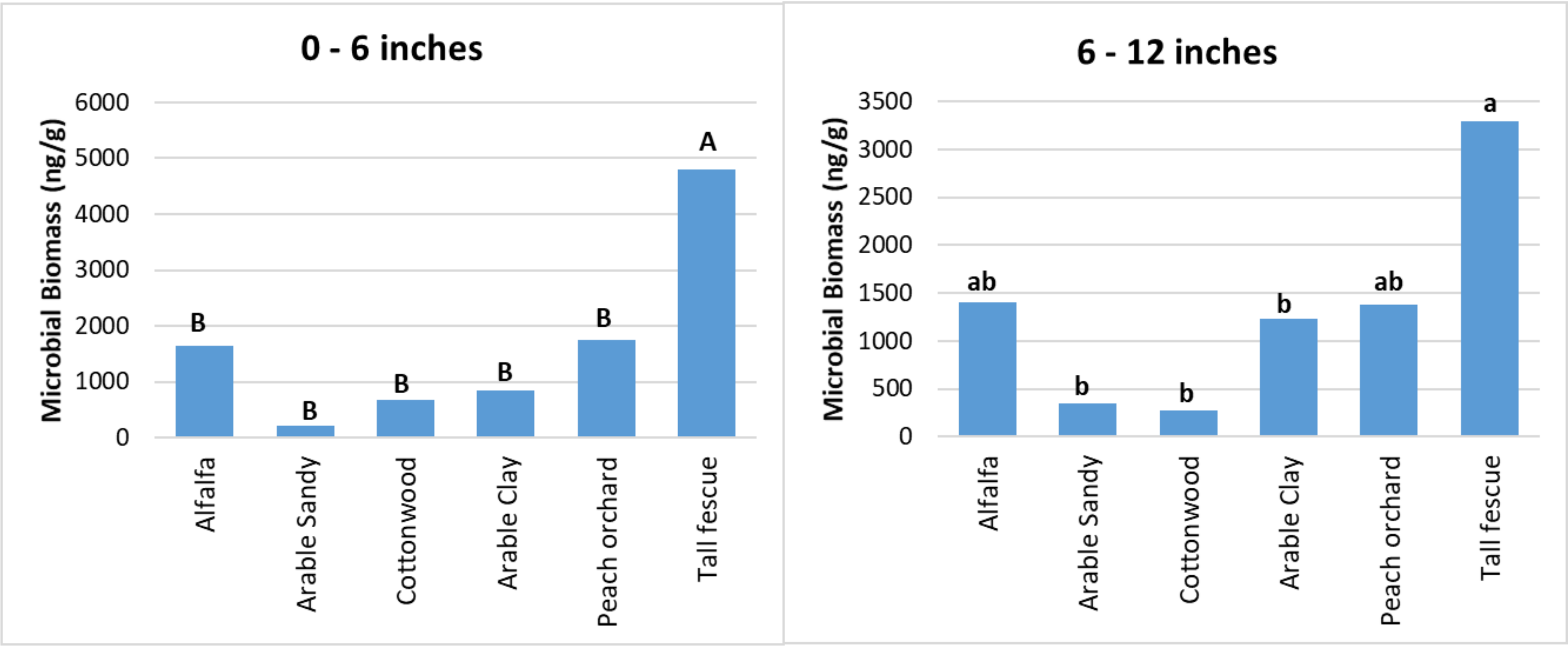
Peach with Clover Understory

Management Systems and Measurements

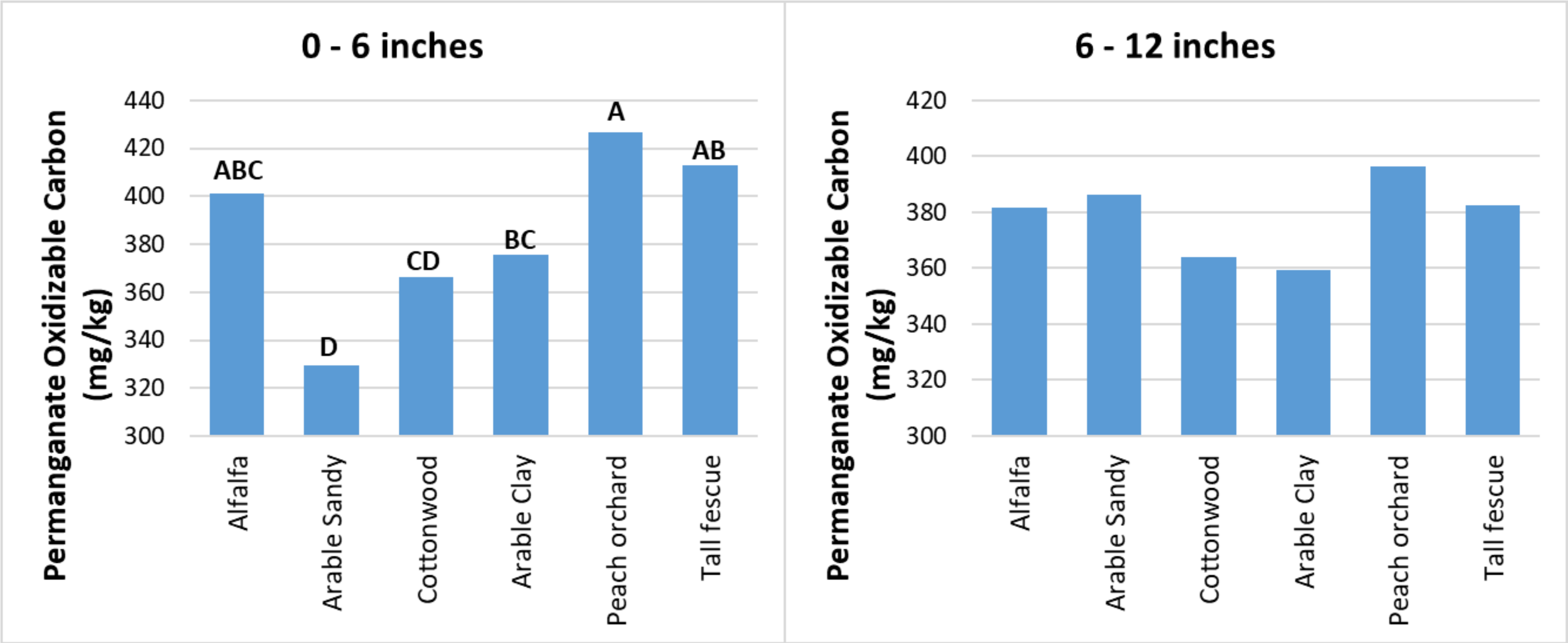
Mean Weight Diameter – Resistance to Wind Erosion



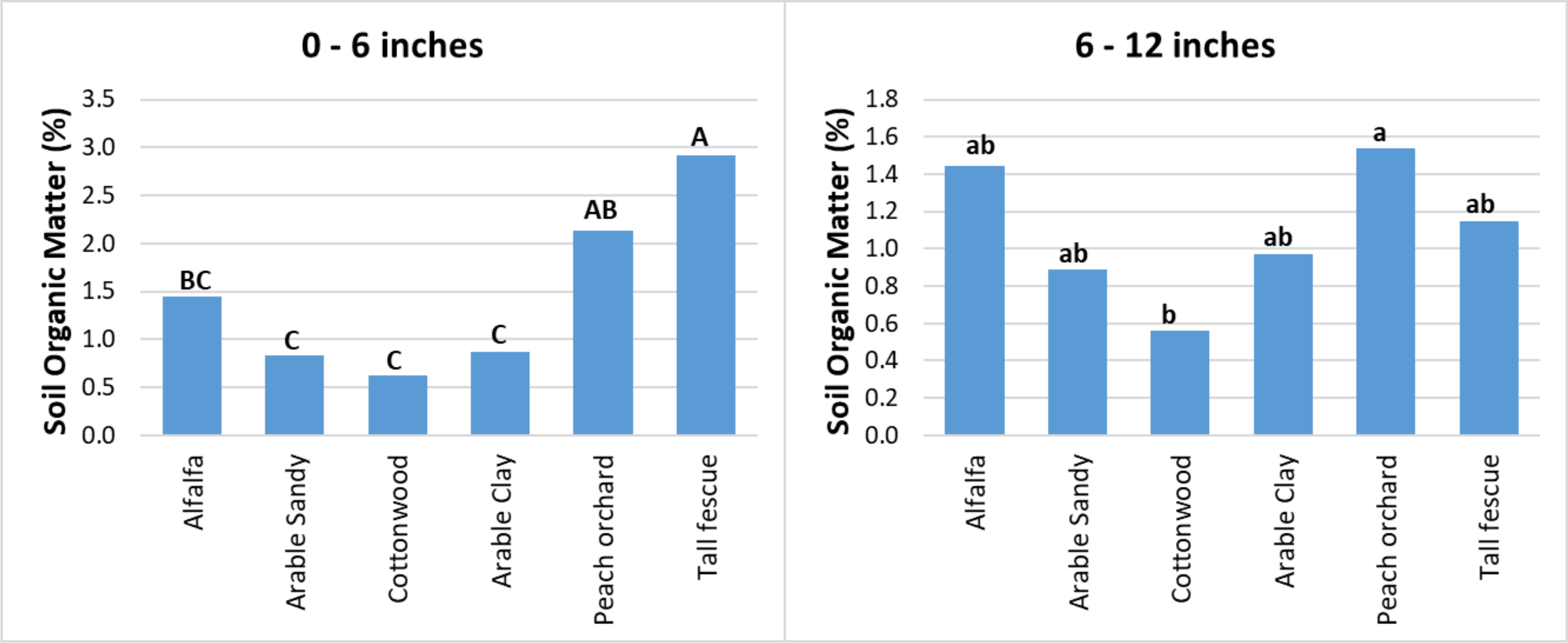
Microbial Biomass in the Soil



Active Carbon – Microbial Food



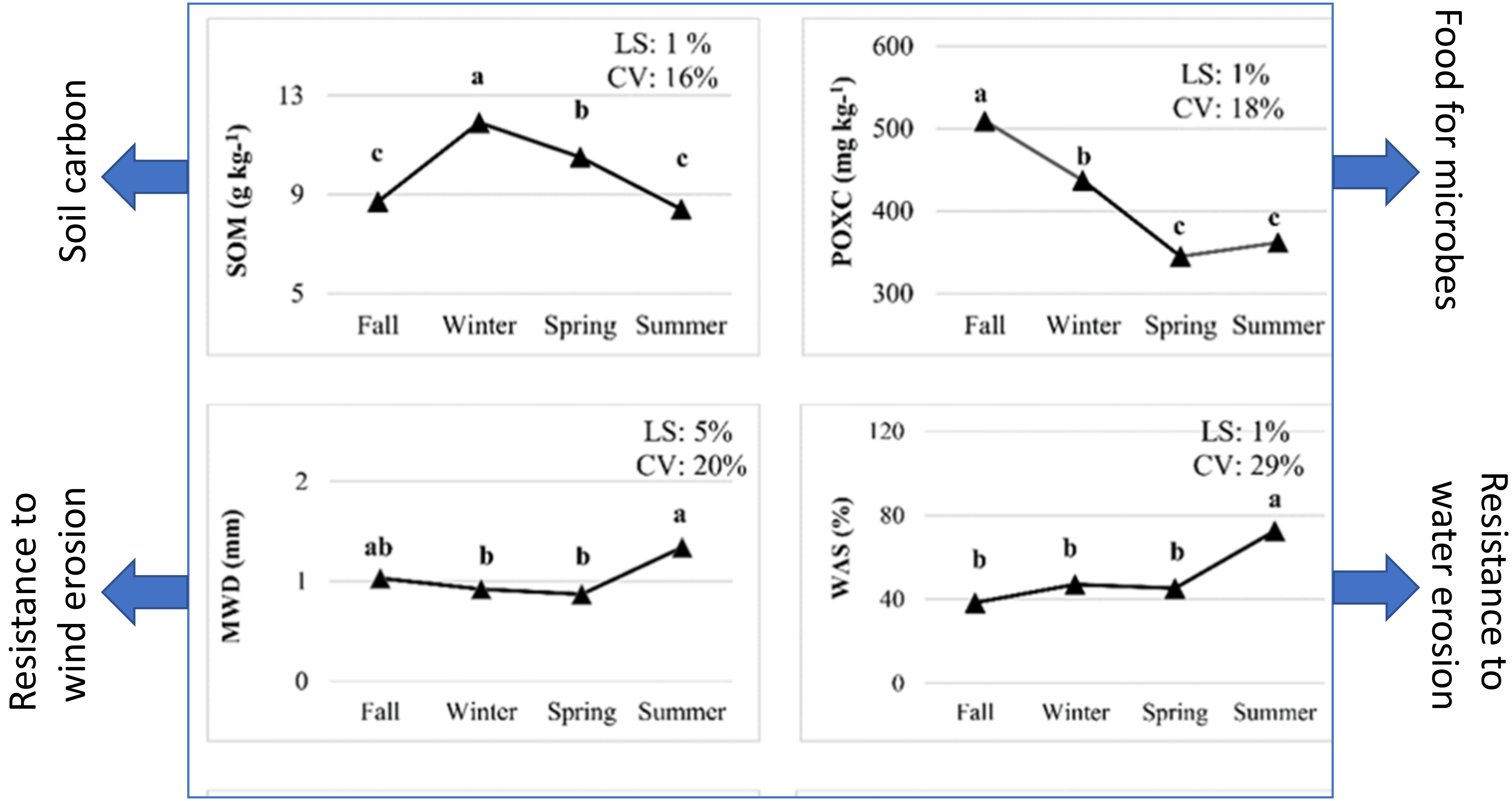
Soil Organic Matter – Soil Carbon



Management Systems and Measurements

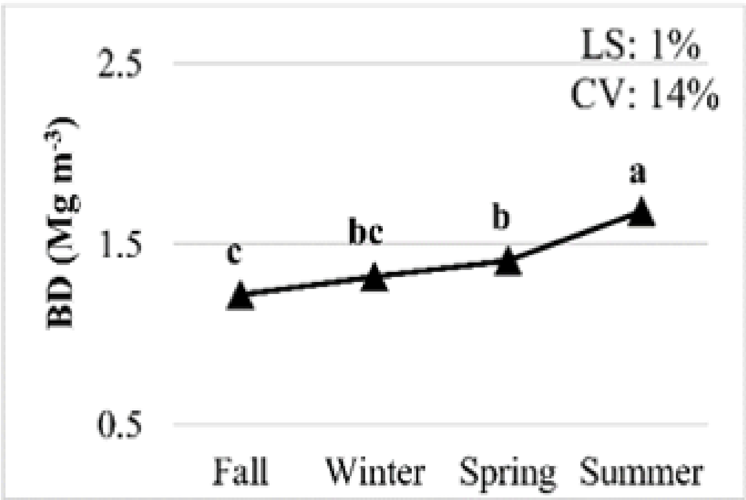
- Soil and crop management systems significantly influenced soil quality indicators at 0 – 6 and 6 – 12 inches.
- Several measurements are available for assessing soil health in arid systems
- More favorable soil measurements occurred under long term and less disturbed agricultural management practices (tall fescue grass fields and peach orchard)
- Management practices in the sandy loam soils had less favorable soil health measurements compared to the clay loam highlighting the importance of texture

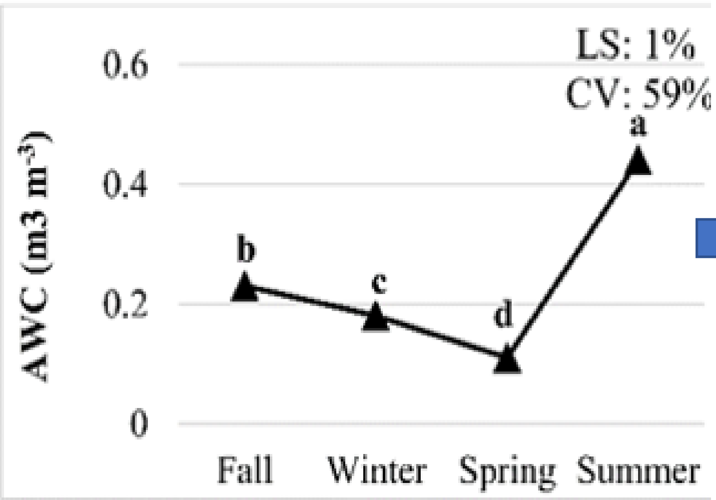
Effect of sampling time



Effect of sampling time

Soil density





Soil moisture retention

- Seasonal effect can act as confounding factor.
- Sampling should be done at around the same time of the year for effective monitoring of soil health.

Omer, M., Idowu, O.J., Ulery, A.L., VanLeeuwen, D. and Guldan, S.J., 2018. Seasonal changes of soil quality indicators in selected arid cropping systems. *Agriculture*, *8*(8), p.124.

Criteria for Selecting Soil Health Indicators

- Based on results of multivariate statistics
- Discussion with experts (Expert opinion)
- Sensitivity to land management
- Precision of measurement method (repeatable measurements)
- Relevance to important functional soil process
- Ease and cost of sampling
- Cost of analysis

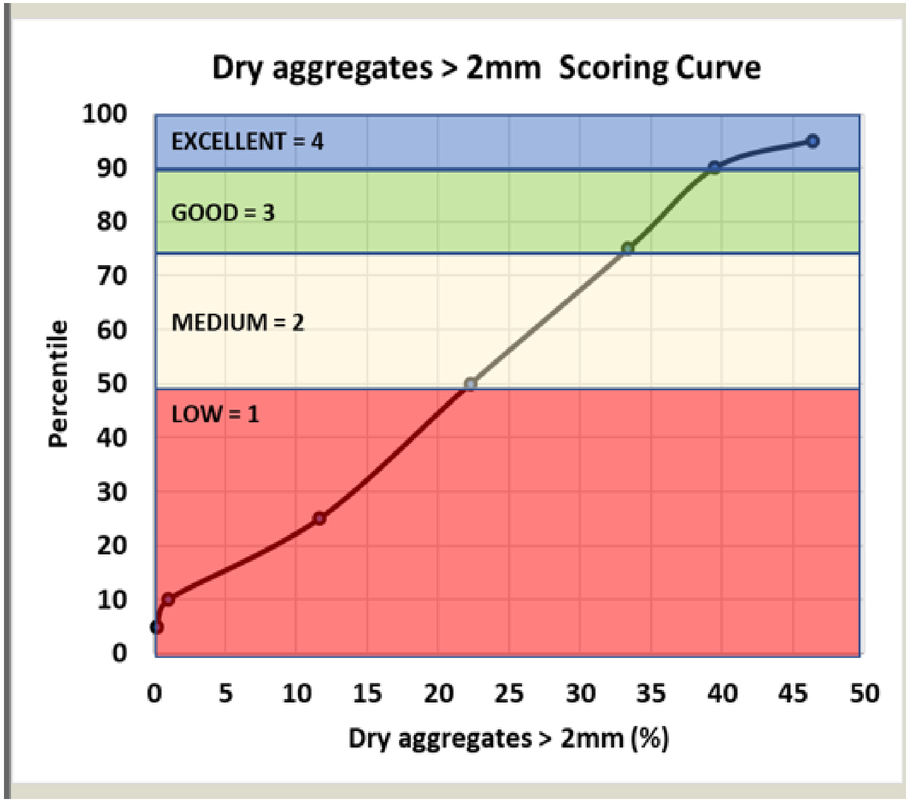
Indicator Selection

PHYSICAL	CHEMICAL	BIOLOGICAL
Dry Aggregates >2mm	Electrical Conductivity	Soil Organic Matter
Clay Content	Phosphorus	Active Carbon (POXC)
Available Water Capacity	Potassium	
Wet Aggregate Stability		
4 Indicators	3 Indicators	2 Indicators

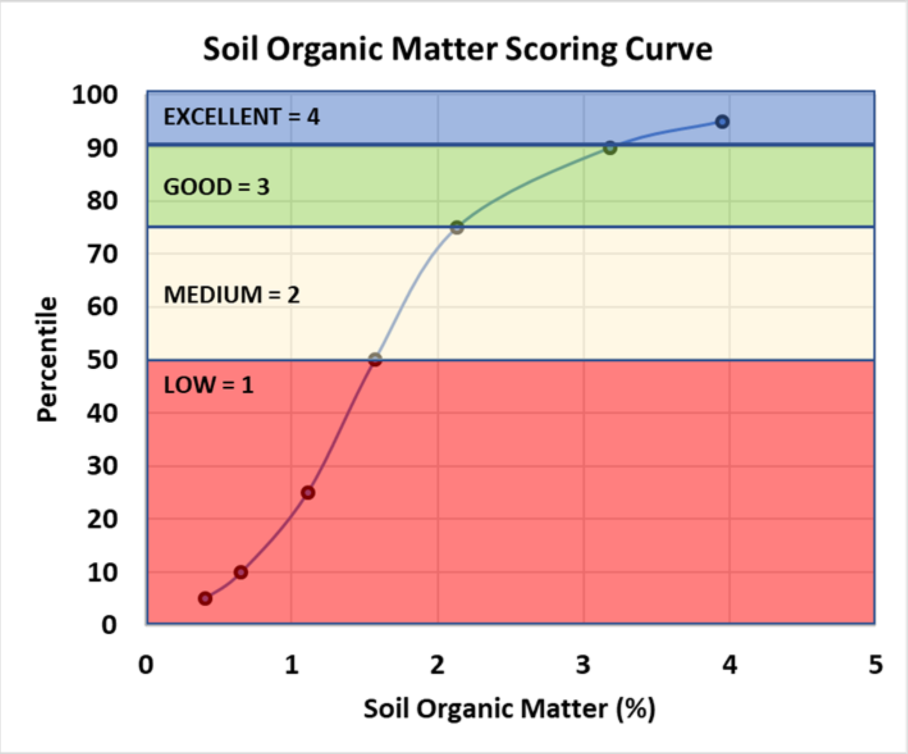
Relationships Among Indicators

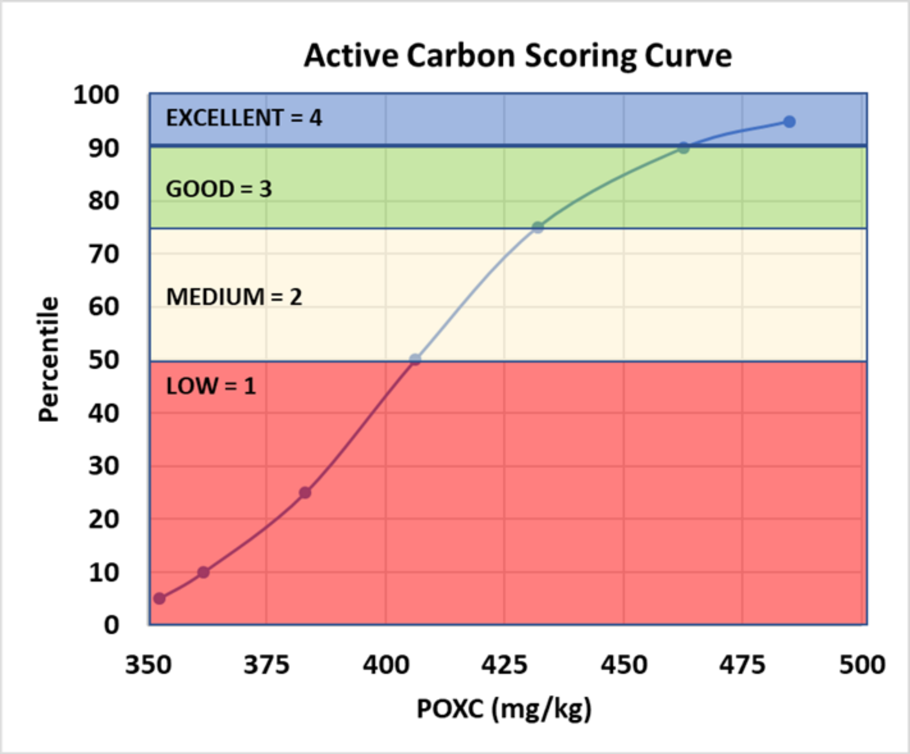
	Biological Measurements	Active Carbon	Wet Aggregate Stability	Soil Organic Matter
1	Total Microbial Biomass (ng/g)	0.59	0.58	0.70
2	Diversity Index	0.36	0.31	0.49
3	Total Bacteria Biomass (ng/g)	0.66	0.56	0.76
4	Actinomycetes Biomass (ng/g)	0.69	0.52	0.80
5	Gram (-) Biomass (ng/g)	0.61	0.56	0.70
6	Rhizobia Biomass (ng/g)	0.51	0.44	0.55
7	Total Fungi Biomass (ng/g)	0.56	0.52	0.68
8	Arbuscular Mycorrhizal Biomass (ng/g)	0.57	0.54	0.71
9	Saprophytes Biomass (ng/g)	0.54	0.50	0.65
10	Protozoa Biomass (ng/g)	0.55	0.47	0.69
11	Gram (+) Biomass (ng/g)	0.70	0.54	0.80
12	Undifferentiated Biomass (ng/g)	0.39	0.51	0.48
13	Fungi:Bacteria	0.15	0.22	0.25
14	Predator:Prey	0.22	0.27	0.30
15	Gram(+):Gram(-)	-0.27	-0.40	-0.19
Number of significant relationships		**12**	**12**	**12**

Interpreting Soil Measurements: Scoring Curves:



Scoring Curves:



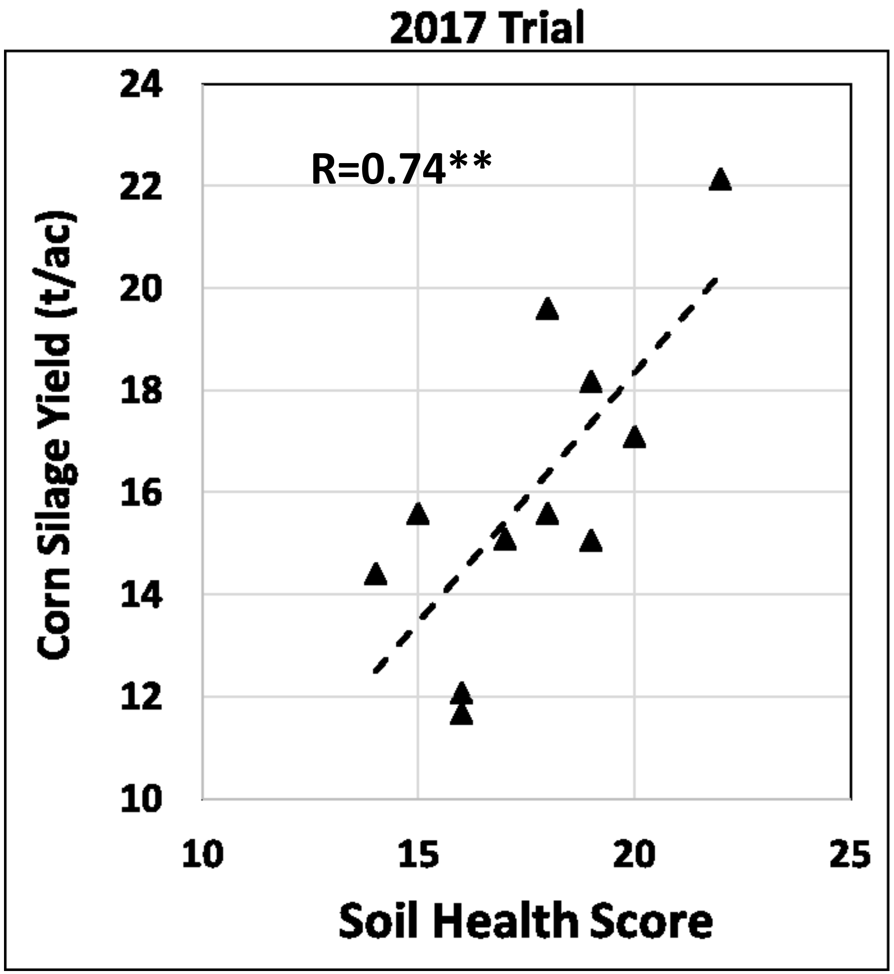


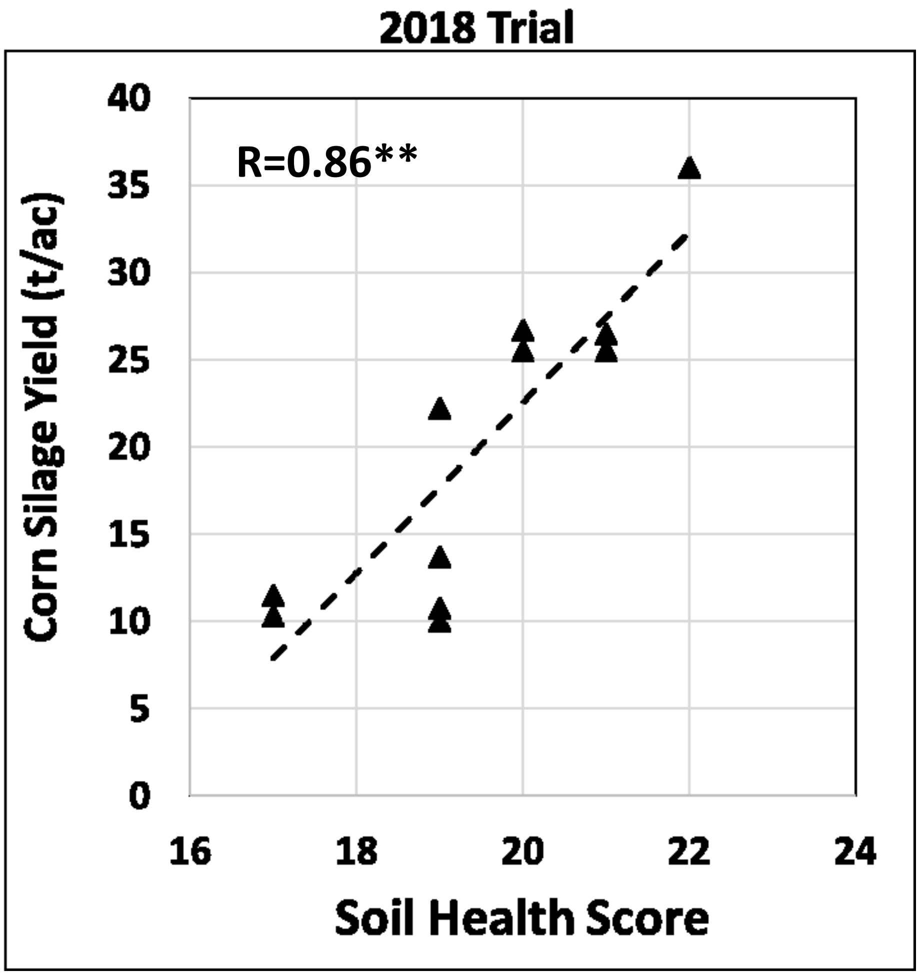
Calculating Soil Health Scores

Plots	POCX Score	AGG>2mm Score	Clay Score	AWC Score	WAS Score	EC Score	SOM Score	K Score	P Score	Soil Health Score
1	2	2	2	3	1	3	2	1	1	17
2	3	2	4	3	1	1	4	1	4	23
3	3	1	2	1	1	3	2	1	3	17
4	4	3	4	2	2	2	4	4	4	29
5	2	4	4	2	3	3	2	1	1	22
6	2	2	4	2	1	3	1	1	1	17
7	2	1	1	3	1	2	1	3	2	16
8	3	4	2	1	1	3	3	1	1	19
9	2	3	2	1	2	4	1	1	1	17
10	3	3	2	2	2	4	3	1	1	21

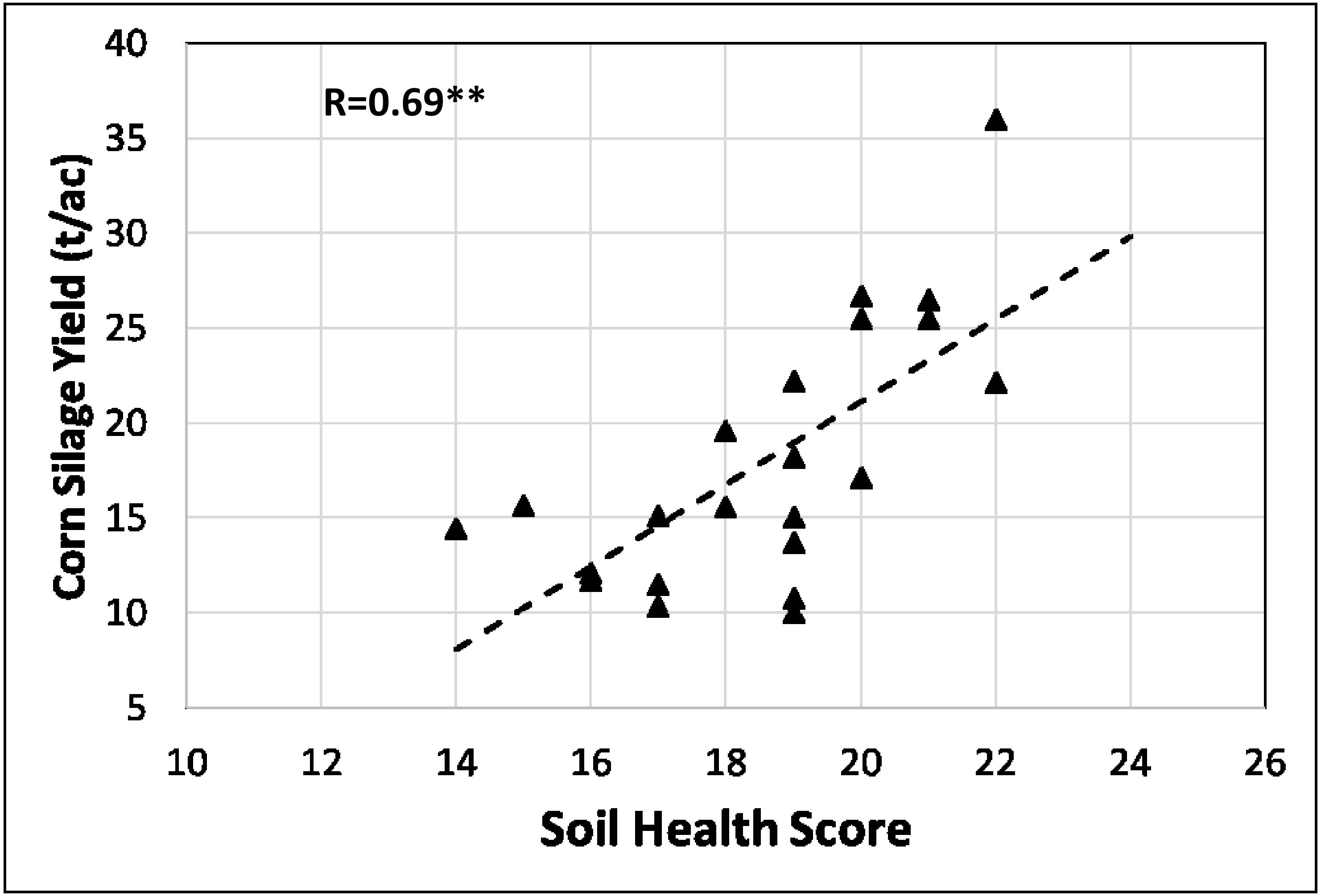
Maximum Soil Health Score = 36

Relationships between Soil Health Scores and Yields





Combined 2017 & 2018 Results



Current & Future Plans:

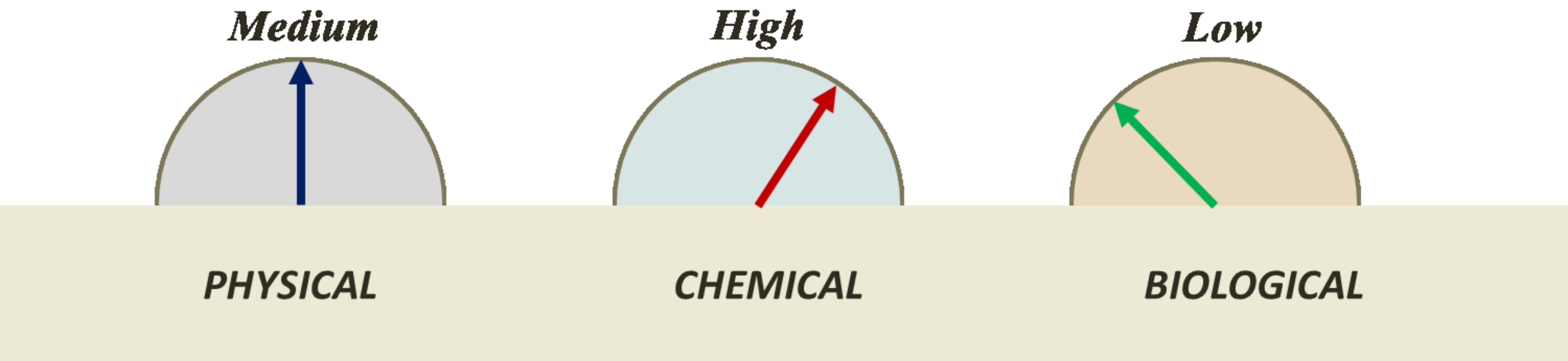
- More validation of the soil health model with yield from farms and experimental plots
- Model scoring curves will be adjusted for other ecosystem services (for example – environmental conservation)
- More studies on how the models can be adjusted based on specific management systems (for example – vegetable vs field crops)
- More farmer involvement in testing the model (through grant funding)

Work in Progress:

Develop farmer friendly assessment framework

- Visually enhanced soil health report format
  - Easy to read
  - Easy to understand
  - Suggestion of management options when there are problems

NM Soil Health Report



Total Soil Health Score: ??

Suggested Management Options: ??

Soil Health Management Strategies

- Reducing tillage
- Cover Cropping
- Crop Rotation
- Organic Amendments

Problems Associated with Intensive Tillage

- Loss of organic matter
- Loss of beneficial soil organisms
- Loss of soil structure and porosity
- Increased soil erosion and pesticide runoff
- Reduced soil fertility (more inputs each year)
- Compaction (formation of plow pans)
- Surface crusting (soil dries out quickly)
- Reduced root growth
- Poor drainage
- Reduced water holding capacity during droughts

Soil Health Management Strategies

REDUCING TILLAGE

- Reducing tillage is very critical to building and maintaining soil health
- Reducing tillage may present some challenges especially in transition years – especially no-till system
- Systems like no-till may underperform during the initial stages but will become better over time (performance may depend on previous land-use history or rotation)
- Strip tillage is a good option for transitioning to no-till – going straight into no-till may lead to yield losses due to compaction

Reduced Tillage Effects on Corn Silage

- Experiment 1: Previous crops – sorghum-sudan in summer and winter wheat in fall over 4 years (cut and bales)
- Experiment 2: Previous crop – Alfalfa for 4 years (6 – 7 cuts/year)
- Winter wheat cover crop preceded the tillage treatments
- Winter wheat cover crop was cut and baled with 8 – 10 inches stubble left in place
- Treatments – Plow-till, Strip-till and No-till
- Corn silage planted in June; Harvested in October
- Soil texture: Clay loam

Plow Till

- Plow-till involved five tillage passes to create a smooth seedbed across the entire plot
  - plow
  - ripping
  - disking twice
  - harrowing

Strip-Till

- Strip tillage (ST) a single pass with a strip tiller creating a seedbed of about 8 inches wide strips

Shank for deep vertical tillage


Strip Tillage
(3 weeks after planting)


No-Tillage
(3 weeks after
planting)


Conventional Tillage
(3 weeks after
planting)

Strip Tillage (6 weeks after planting)

No-Tillage (6 weeks after planting)

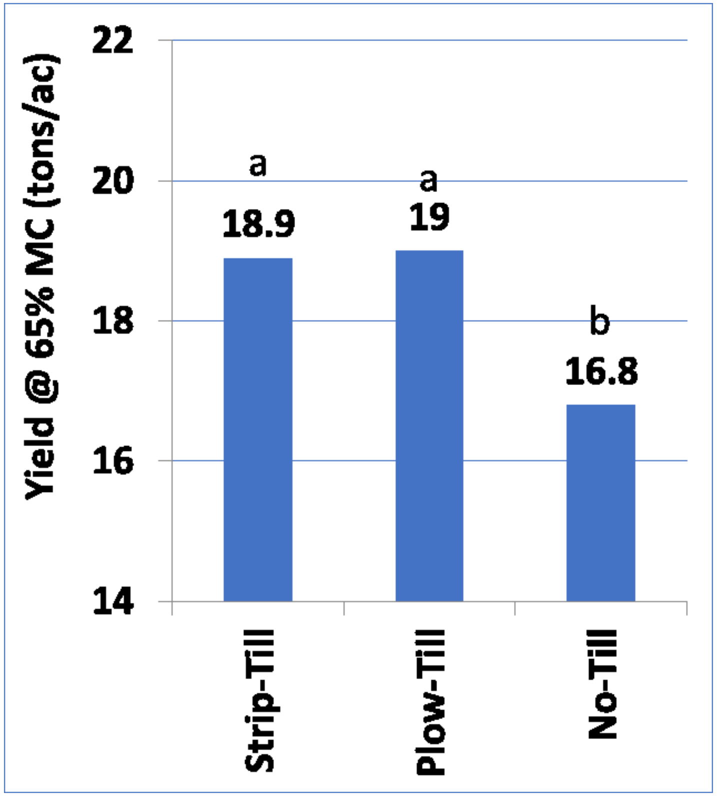
Conventional Tillage (6 weeks after planting)

Surface Crusting and Drying out of soil

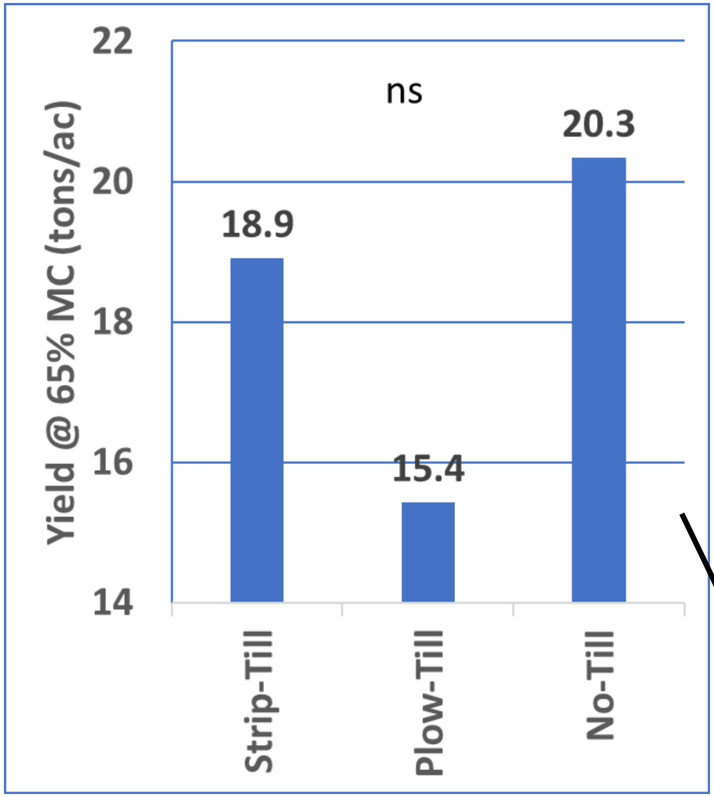
Surface Residue Minimizes Crusting

Corn Silage Yields – Different Rotations

After Sorghum-sudan – Winter wheat rotation



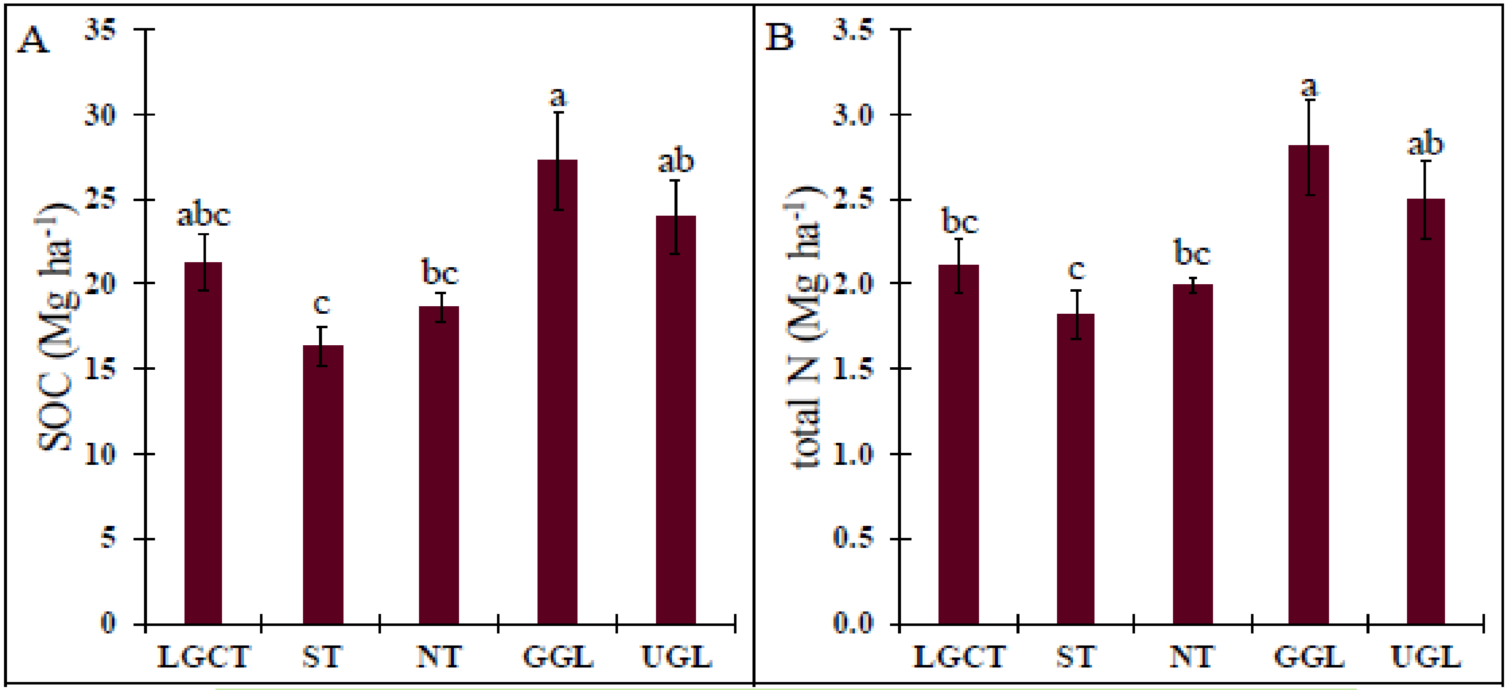
After Alfalfa rotation



Idowu, O.J., Sultana, S., Darapuneni, M., Beck, L. and Steiner, R., 2019. Short-term conservation tillage effects on corn silage yield and soil quality in an irrigated, arid agroecosystem. *Agronomy*, *9*(8), p.455.

No-till Corn Close to Harvest – Alfalfa Rotation.

Land Use: Cropland Vs. Grassland



Croplands	Grasslands
Livestock grazed conventional tillage (LGCT)	Grazed grassland (GGL)
Strip tillage (ST)	Ungrazed grassland (UGL)
No-tillage (NT)	

Thapa, V.R., Ghimire, R., Mikha, M.M., Idowu, O.J. and Marsalis, M.A., 2018. Land Use Effects on soil health in semiarid drylands. *Agricultural & Environmental Letters*, *3*(1).

Cover Crop Benefits

- Cover crops can help prevent erosion
- Reduce leaching of nutrients by serving as catch crops
- Help alleviate soil compaction
- Help suppress perennial and winter annual weeds
- Add organic matter to the soil

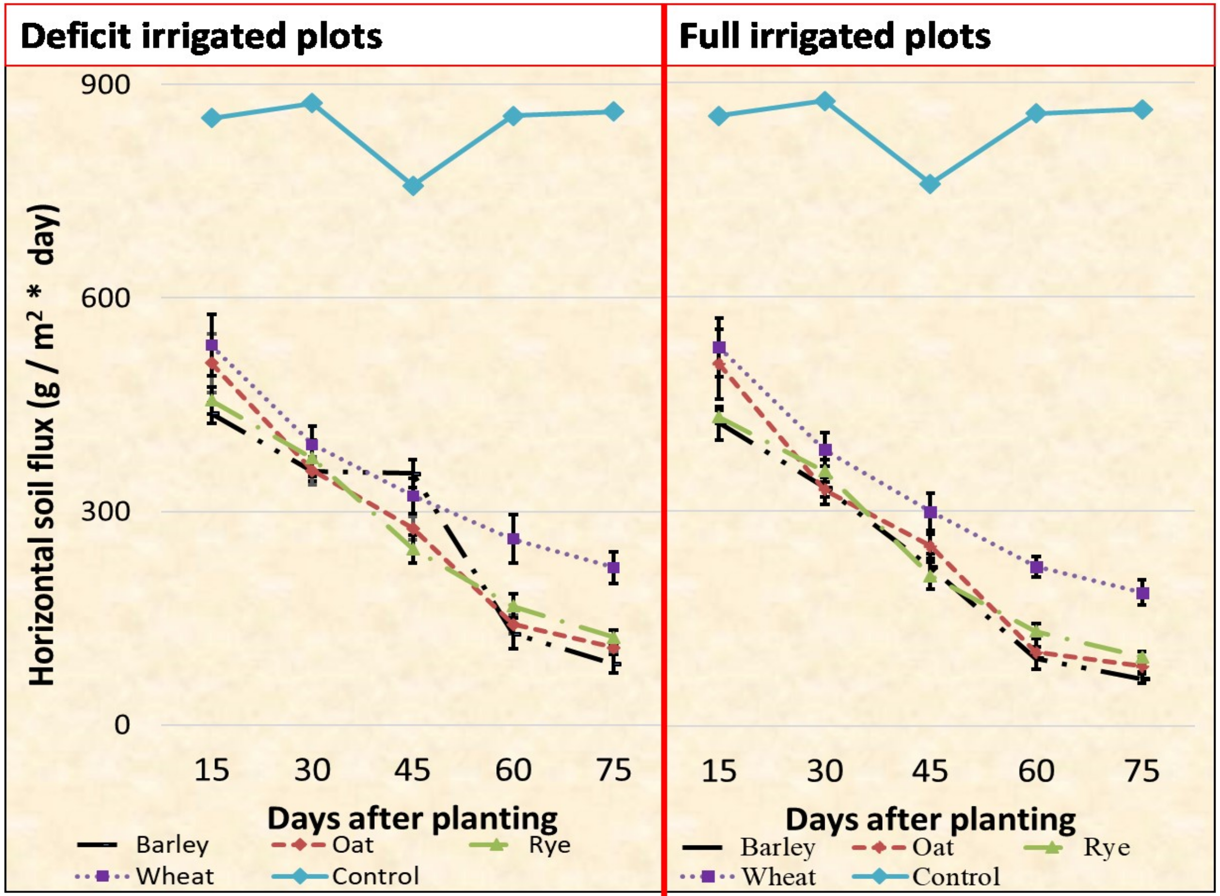
Using Cover Crop in Arid/Semiarid Southwest

CHALLENGES

- Management of cover crops is key to success
- Cost of seed and establishment (long-term investment)
- Water consumption of cover crop growth may reduce soil moisture and harm the following cash crop
- May reduce soil temperature and cause slow growth in cooler regions (if residue is heavy)
- May harbor certain insects and disease that affect surrounding plants and vegetation

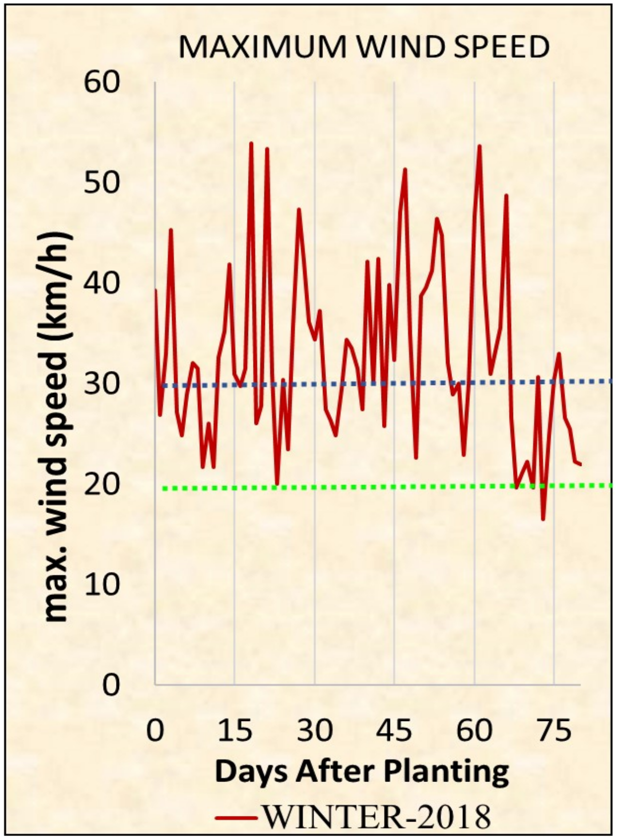
Winter Cover Crops and Soil Erosion

February 14 – May 5



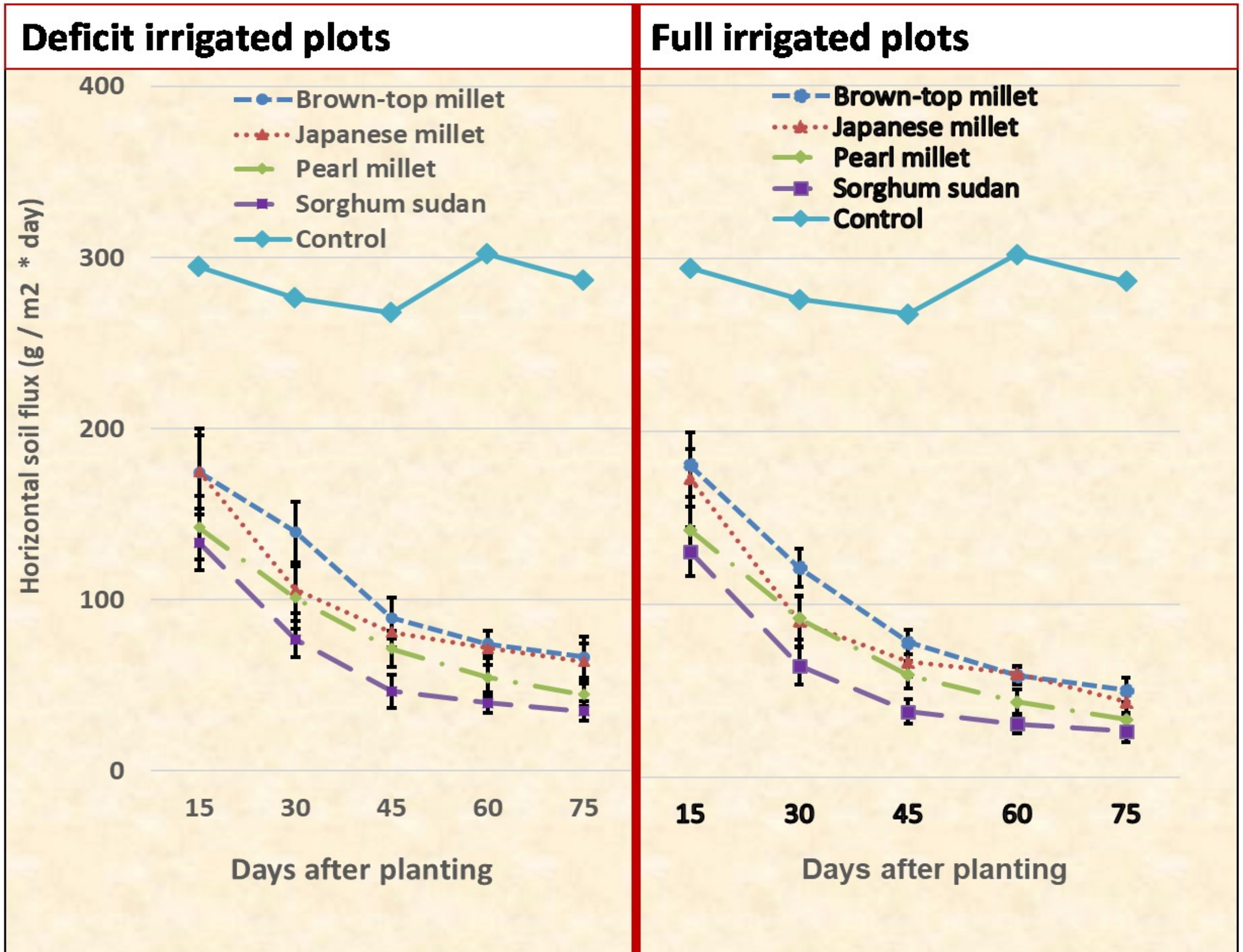
10 inches

20 inches



Winter cover crops led to 90% reduction in wind erosion

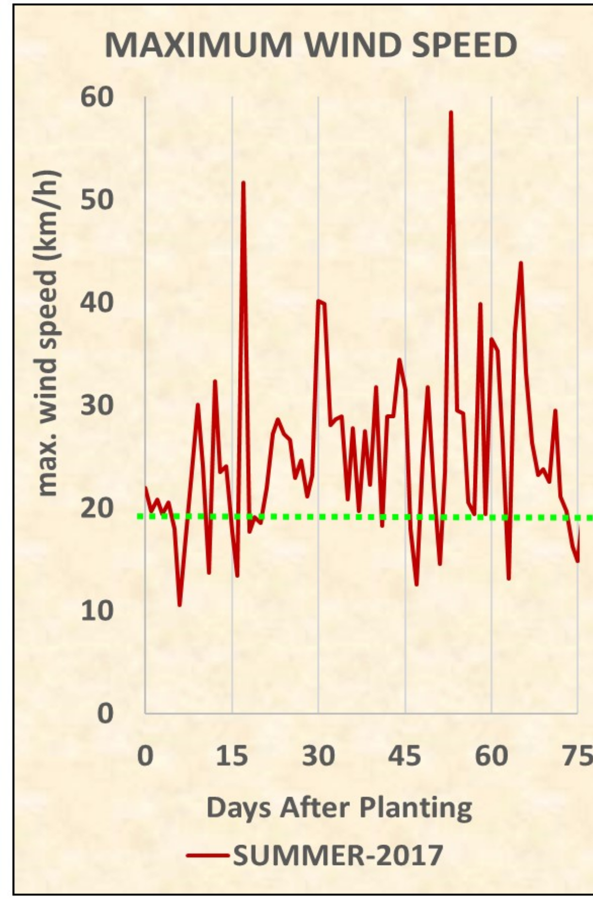
Summer Cover Crops and Soil Erosion



10 inches

20 inches

August 27 – November 13



Summer cover crops led to 90% reduction in wind erosion

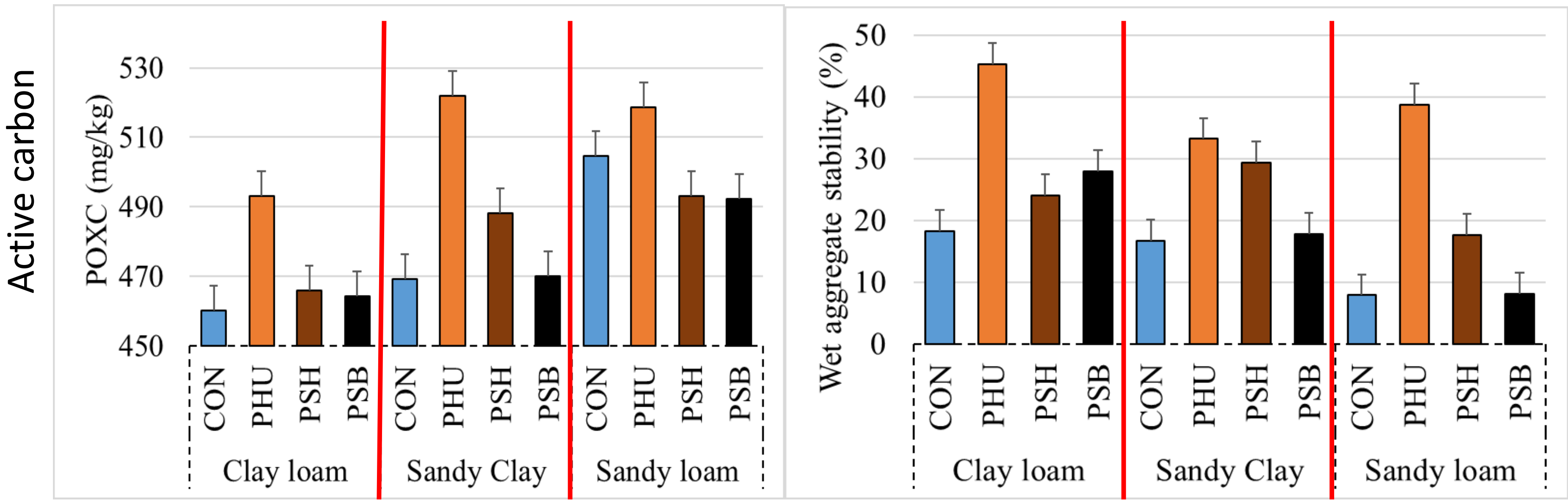
Organic Amendments

- Organic amendments can
  - help build up the soil organic matter
  - Provide nutrients for soil fertility improvement
  - Increase the soil microbial abundance and diversity
  - Help recycle waste
- Examples include materials from plant or animal origin such as manure, compost, biochar, etc.
- Although a good source of OM, but has some limitations:
  - Availability and transport
  - Cost of materials
  - Quality of product
  - Performance in different soil types could be variable

Using Pecan Waste to Amend Soil

An abundant waste in southwestern NM

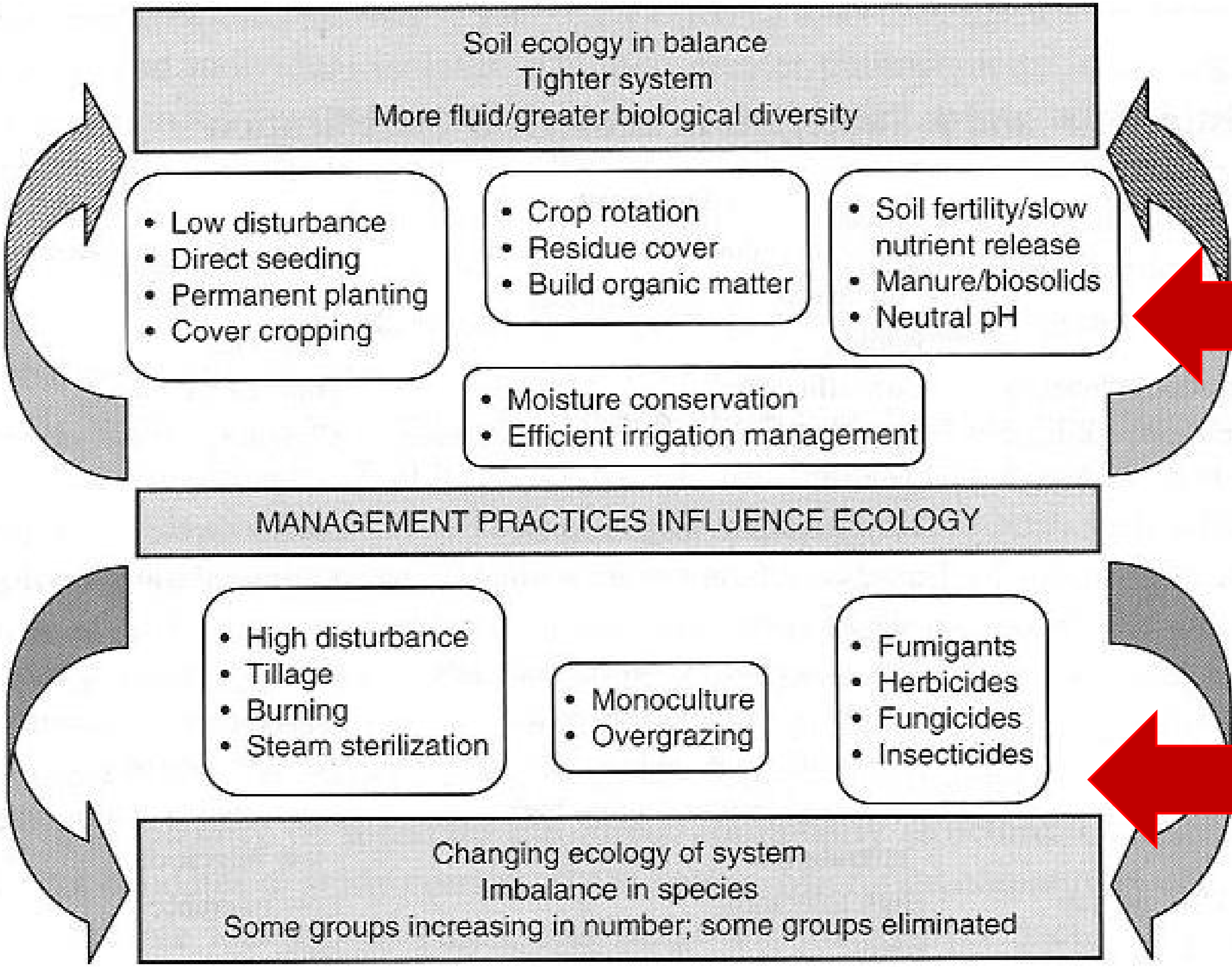
4 Weeks Incubation Study (20 t/ac)



CON: control treatment; PHU: pecan husk; PSH: pecan shell; and PSB: pecan shell biochar

Idowu, O.J., Sanogo, S. and Brewer, C.E., 2017. Short-Term Impacts of Pecan Waste By-Products on Soil Quality in Texturally Different Arid Soils. *Communications in Soil Science and Plant Analysis*, *48*(15), pp.1781-1791.

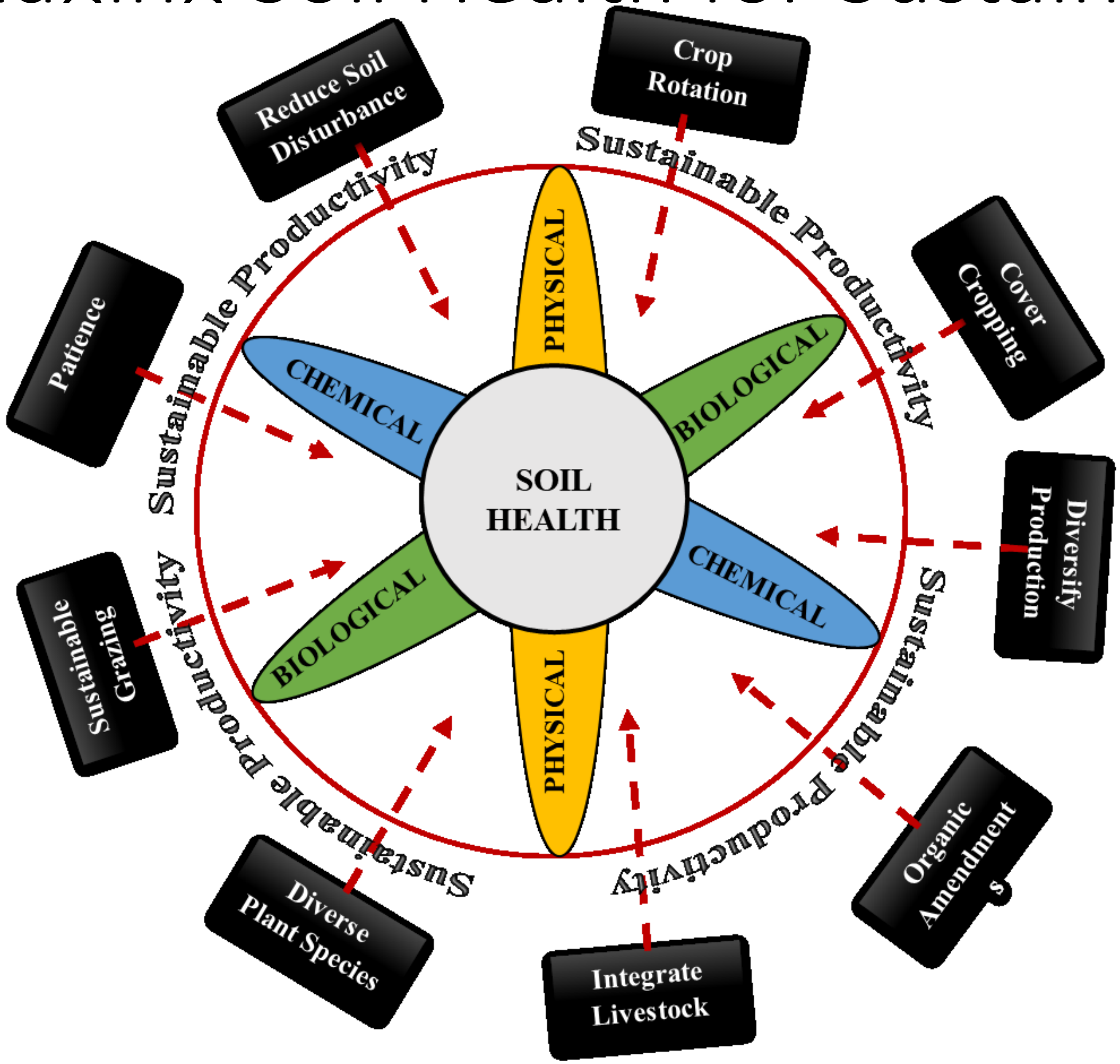
Ecological Approach to Farming



Favors microbial diversity

Does not favor microbial diversity

Managing Soil Health for Sustainability



Idowu, J., Ghimire, R., Flynn, R. and Ganguli, A., (2020) Soil Health—Importance, Assessment, and Management. NMSU Cooperative Extension Service Circular 694B


Thanks