

The Scientific System of Soil Health



The Science of Soil Health



- **Soil Health is an emerging science developed in the recent two decades**
- **Soil Health is a branch of Soil Science under Agricultural Science in Natural Science**

The Science of Soil Health

Science is the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence

Science is the systematic study of the structure and behavior of the physical and natural world through observation, experimentation, and the testing of theories against the evidence obtained

	Science		
	Formal science	Empirical sciences	
		Natural science	Social science
Foundation	Logic; Mathematics; Statistics	Physics; Chemistry; Biology; Earth science; Space science	Economics; Political science; Sociology; Psychology
Application	Computer science	Engineering; Agricultural science; Medicine; Dentistry; Pharmacy	Business administration; Jurisprudence; Pedagogy

Agriculture

The science, art, & business of cultivating soil, producing crops, and raising livestock

Soil science

The branch of science concerned with the formation, nature, ecology, and classification of soil

The study of the formation and distribution of soil, the physical, chemical and biological properties and processes of soil and how these processes interact with wider systems to help inform environmental management, industry and sustainable development

Liberal arts and sciences

The subjects & skills essential for a free person to know to take an active part in civic life, including *Literature, Philosophy, Mathematics, and Social & Physical Sciences (Anthropology, Archaeology, Communication, Economics, Psychology, Sociology, Political Science, Linguistics, History, Music, Human Geography, Physics, Chemistry, Biology, Earth Science, Space Science)*



Agricultural inputs

- Land
- Seeds
- Machinery
- Irrigation water
- Fertilizers
- Pesticides
- Power
- Labor

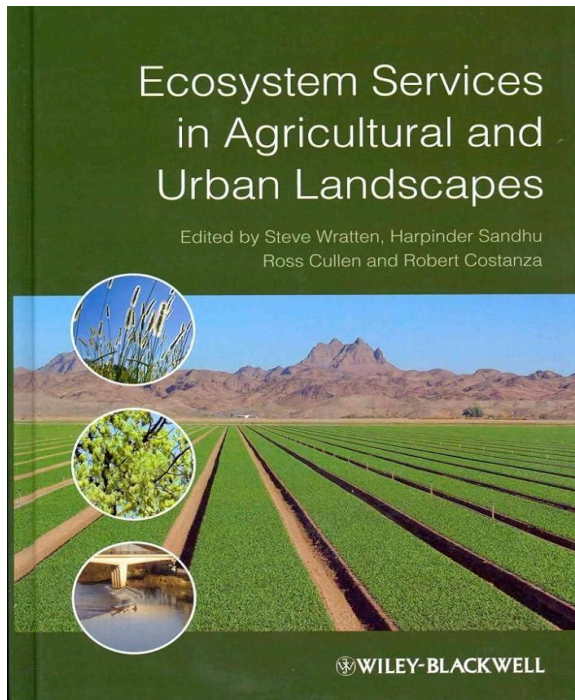
Agricultural outputs

- Food
- Fiber
- Feed/fodder/forage
- Fuel (biomass)

Forces shaping agriculture

- ❖ The integration of global markets
- ❖ The concern for the environmental impact of agriculture
- ❖ The effects of climate change
- ❖ The effects of growing consumer influence
- ❖ The push for local and organic foods
- ❖ The need to respond to the increasing rates of obesity
- ❖ The changing demographics of the ag workforce





Ecosystem services from agriculture

- Provide food, fiber, & fuels
- Stabilize climate
- Supply clean water
- Enhance biodiversity (↑ Pollination & ↓ pests)
- Improve soil fertility



Modern intensive farming

Disservices from agriculture

- Soil erosion
- Water contamination (eutrophication)
- Air contamination (dust & odor)
- OM decomposition
- Greenhouse gas emissions

Agricultural Sciences

Soil science

- Pedology
- Soil Physics
- Soil Chemistry
- Soil Microbiology
- Soil Mineralogy
- Soil Management

Plant science

- Plant Physiology
- Plant Pathology
- Plant Protection
- Plant Breeding & Genetics

Forestry (silviculture)

Crop Science

Turfgrass Sci.

Agronomy

Horticulture

Vit/niculture (grape & wine)

Weed Science

Seed Science

- Floriculture
- Landscaping
- Olericulture (veg.)
- Pomology (fruit)

Animal science

Livestock Sci.

Dairy Science

Poultry Science

Swine Science

Equine Science

Beef Prod. & Manag.

Poultry Prod. & Manag.

Small Ruminant P & M

Apiculture (beekeeping)

Aquaculture

Sericulture (silk)

Vermiculture (worms)

Ag Engineering

Ag Economics

Ag Business/ Education/ Biotechnology/ Chemistry



Bread

From Field to Table

The bread has taken a long journey to arrive at your kitchen table

- ✓ **Research & breeding**
- ✓ **Land & soil cultivation**
- ✓ **Planting, fertilization, & pest control**
- ✓ **Wheat grain harvest**
- ✓ **Transportation & storage**
- ✓ **Milling to flour**
- ✓ **Baking to bread**
- ✓ **Enjoyment on table**



*The Journey of
Rice
From Paddy to Plate*

- ✓ Research & breeding
- ✓ Seedling preparation
- ✓ Paddy soil cultivation
- ✓ Transplanting
- ✓ Fertilization & pest control
- ✓ Harvesting
- ✓ Transportation & storage
- ✓ Hulling, milling & enriching
- ✓ Cooking



Review

Soil Health Assessment and Management: Recent Development in Science and Practices

Mingxin Guo

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Abstract: In the past decade soil health has been intensively studied as a science and practiced as a means to help improve the global social, environmental, and economic sustainability. This paper reviews the recent advances of the scientific soil health system. The current understanding and interpretation of soil health from the perspectives of soil functions, processes, and properties is summarized. Multi-tier soil health indicators were selected from relevant soil physical, chemical, and biological parameters. A suite of soil health assessment methods have been developed, such as soil health card, Solvita soil health tests, Haney soil health test, and comprehensive assessment of soil health. An array of soil health management practices have been recommended, including proper land use, crop rotation, cover crops, conservation tillage, soil organic amendment, crop-range-livestock integration, and rotational grazing. Overall, the recom-

Outlines

- 1. Conceptual evolution of soil health**
- 2. Scientific understanding of soil health**
- 3. Soil health assessment methods**
- 4. Soil health management practices**

Conceptual evolution of soil health



- **First mentioned in 1910 by Henry A. Wallace**
In a thesis to describe soil fertility
Wallace (1888-1965): a graduate of Iowa State College, the 11th Secretary of Agriculture (1932-1936) and the 33rd vice president (1941-1945) of the U.S.
- **Occasionally used by USDA in 1930s**
1936 *Soil Health and National Wealth* to promote soil fertility & nutrient management
- **Proposed for “soil quality” by Doran in 1994**
Soil quality: The capacity of a soil to function, within natural or managed ecosystem boundaries, to sustain plant & animal productivity, maintain or enhance water & air quality, and support human health & habitation
- **Adopted by farmers in 2000s**
In analogy to human health
- **Generalized to the public in 2010s**
2007-2008 food crisis and climate change; soil health covers all aspects of soil
- **Replacing “soil quality”**
“Soil health” dominates in publications

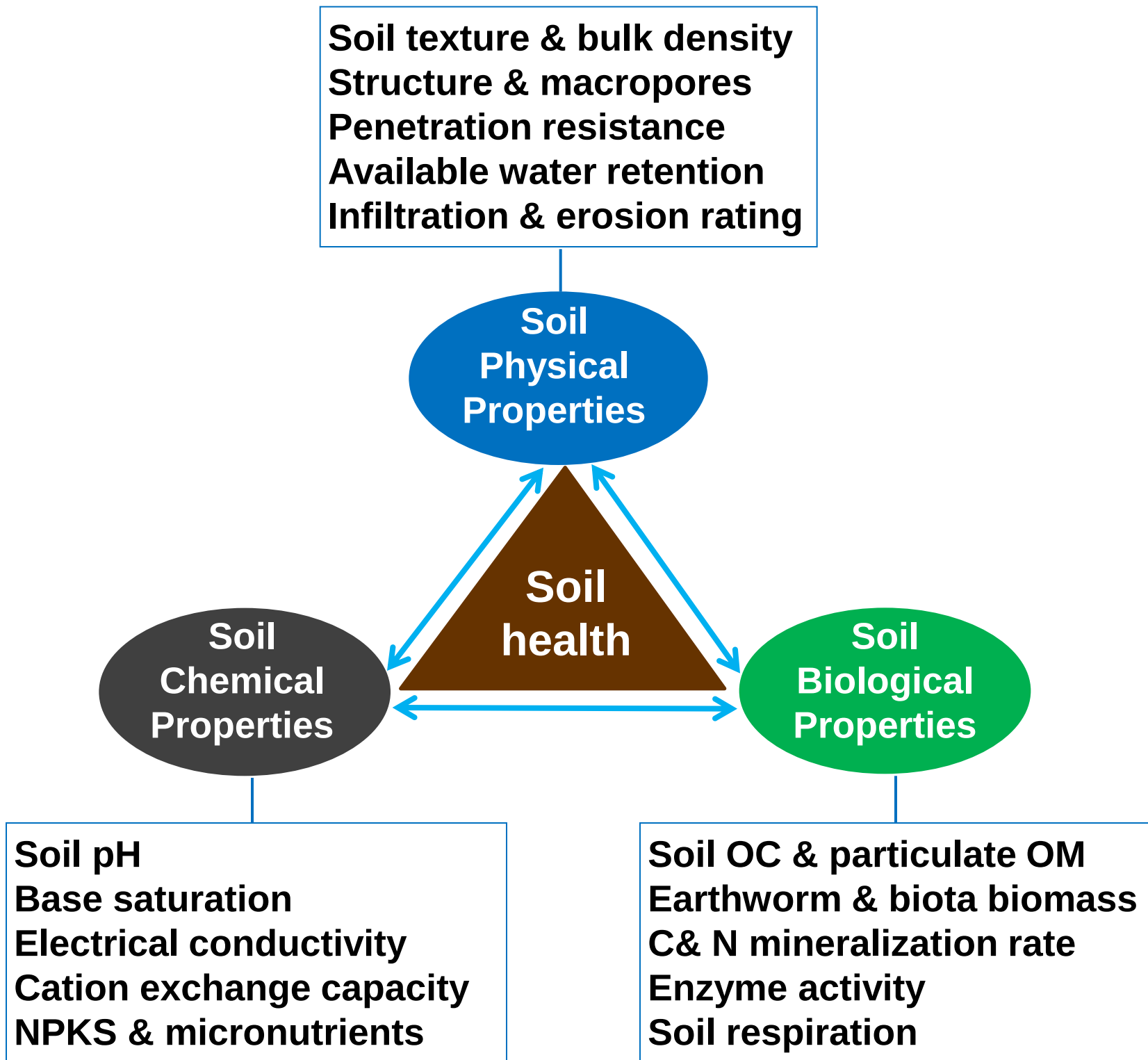
Conceptual evolution of soil health



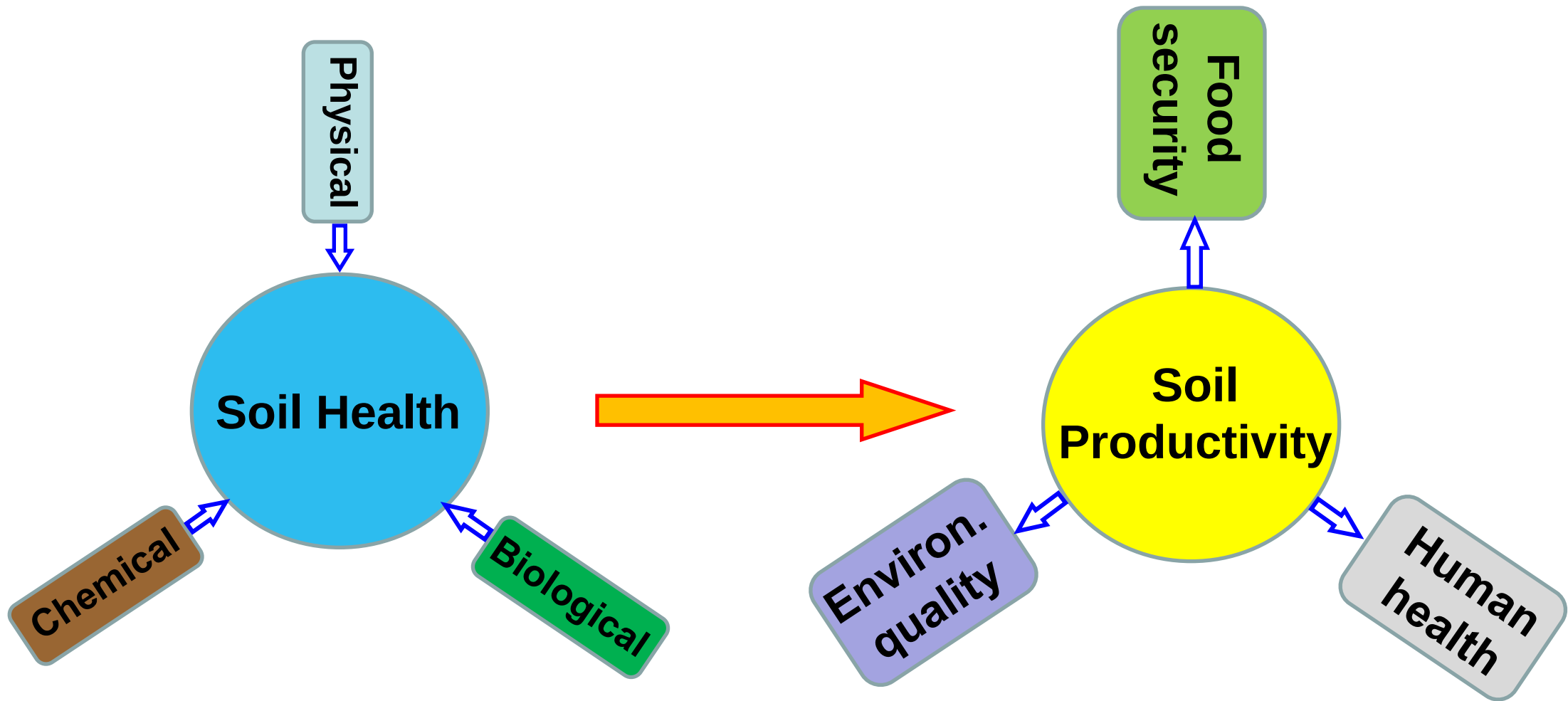
Soil health, or soil “well-being”, is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans – USDA NRCS

Soil is viewed as a living entity in analogy with an organism or a community that can be evaluated by healthiness

As a living ecosystem, soil can be healthy or unhealthy, indicated by how well the soil performs its environmental functions and ecosystem services

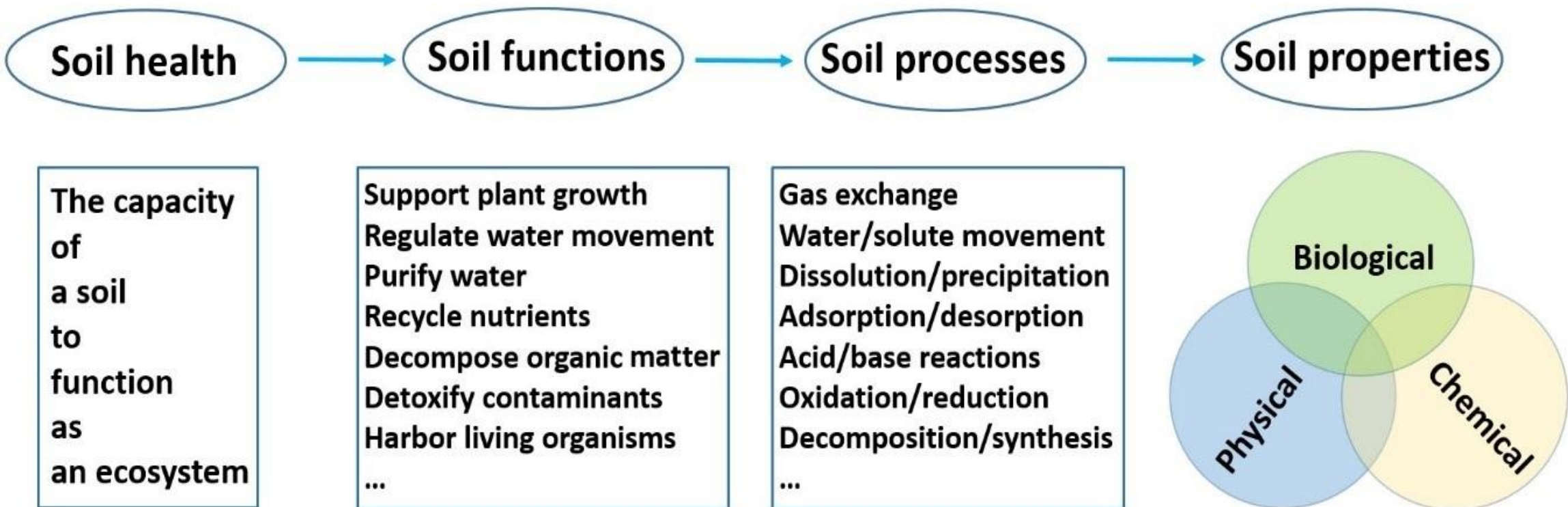


The health of a soil is determined by its properties



The health of a soil determines its productivity

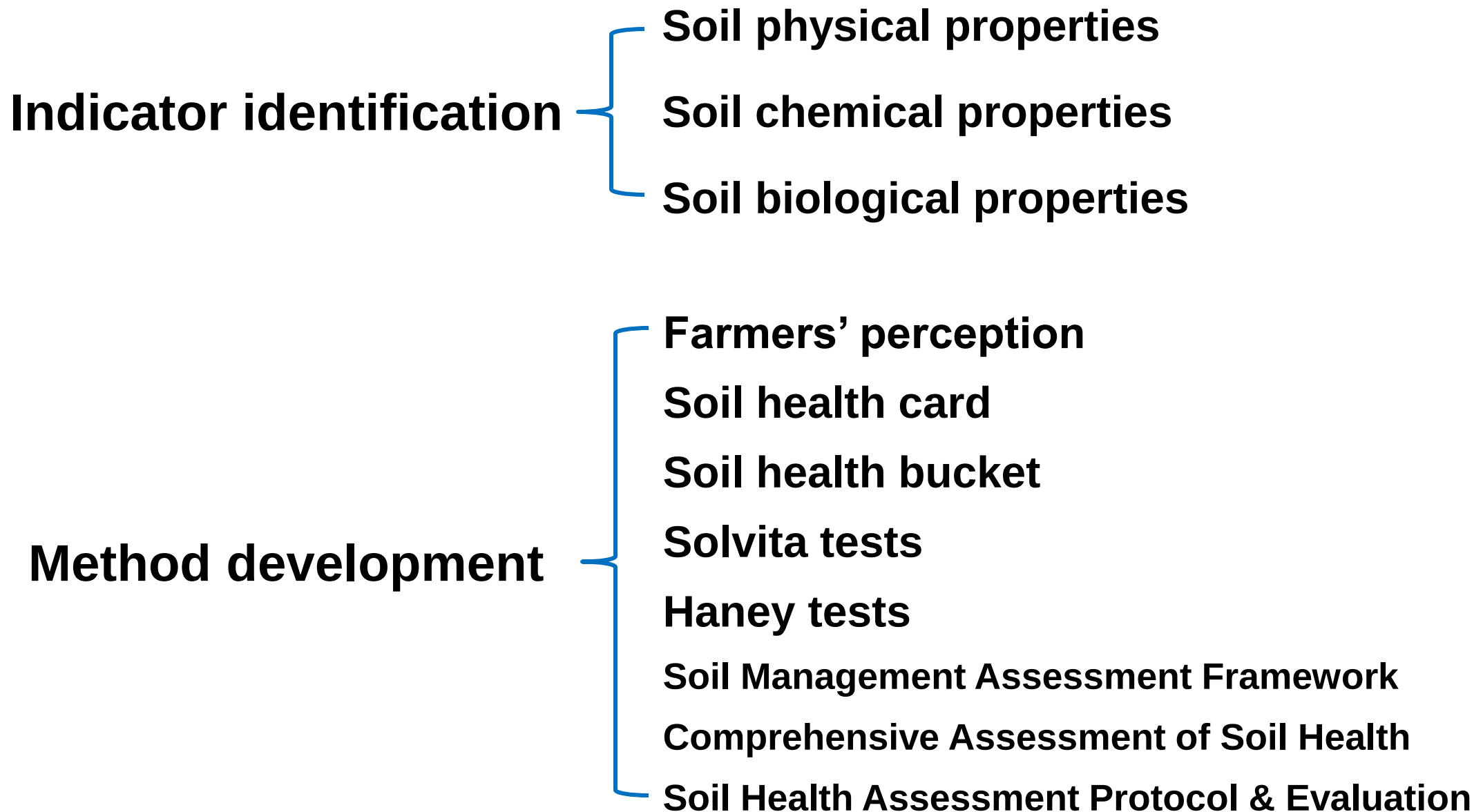
Scientific understanding of soil health



Soil health assessment



- **Identify soil health indicators**
- **Develop soil health assessment methods and criteria**



Criteria for soil health indicators

- 1) The ability to indicate soil function changes**
- 2) Ease of sampling and measurement**
- 3) Accessibility and interpretability to general users**
- 4) Applicability to field conditions**
- 5) Sensitivity to climate and management variations**

Soil Health Indicators	Criteria	Examples
Tier 1	• Widely considered effective to indicate SH • Known thresholds to index outcome-based SH status • Responsive to land use and management practices for soil function improvement	Soil texture, bulk density, aggregate stability Available water-holding capacity Saturated hydraulic conductivity Soil pH, EC, CEC, and base saturation Extractable P, Ca, Mg, K, Fe, Mn, Cu, Zn Extractable Al, As, B, Ba, Cd, Co, Cr, Mo, Ni, Pb, Si, Sr Soil total nitrogen content Nitrogen mineralization rate Soil organic carbon content Short-term carbon mineralization Crop yield
Tier 2	• Proven relevant to SH • Ranges and outcome-based thresholds are known for some regions • Research needed for further validation	Soil sodium adsorption ratio Macro-aggregate stability Soil stability index, protein index, active C content Soil β -glucosidase, acrylsulfatase Soil N-acetyl- β -D glucosaminidase Soil phosphomonoesterase Soil phospholipid fatty acid (PLFA) profile Soil fatty acid methyl ester (FAME) profile Soil microbial genomics, reflectance
Tier 3	• Potential as a SH indicator • More research is needed	Soil microbial community structure Soil microbial DNA extraction and sequencing

Farmers' perception of soil health



Using senses: watch, touch, smell

- Crop performance
- Soil color
- Soil structure (soft crumbly)
- Soil crusting
- Soil compaction
- Ease of tillage
- Soil infiltration
- Soil drainage
- Soil aroma (sour putrid vs. earthy sweet)

Symptoms of unhealthy soils

Sick soil syndromes

- 1) Poor plant growth
- 2) Lower than normal crop yield
- 3) Light in color
- 4) Water logging after heavy rain
- 5) Surface crusting after rain
- 6) Large plow clods
- 7) Low drought resistance
- 8) Dominance of weeds, pests, & disease
- 9) Unsafe food and water products
- 10) Severe wind and water erosion

Be a soil doctor



Soil health assessment

Field evaluation: Soil health card

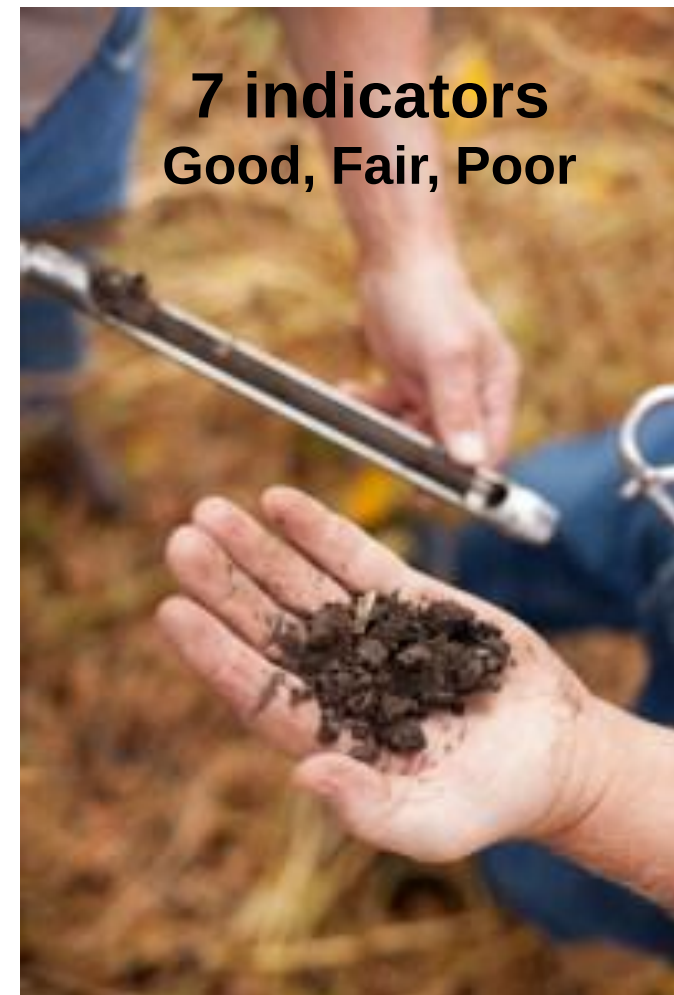
MARYLAND SOIL HEALTH CARD

Farm/Tract/Field #s.: _____	Date: _____
Current Tillage System with number and kind of crops in rotation: _____	Assisted by: _____ Soil Texture: _____

Indicators	Descriptive Ratings		
	Good	Fair	Poor
Surface Residue	>60% visible at various stages of decomposition on soil surface ☐	30-60% visible, non-decomposed residue on soil surface ☐	0-30% visible non-decomposed residue on soil surface. ☐
Infiltration (Based on soil texture) (Refer to Infiltration Chart)	Higher infiltration rate indicates soil absorbs water in a timely manner and is not susceptible to runoff or ponding. ☐	Average infiltration rate indicates soil absorbs water, but more slowly, and runoff and ponding may occur. ☐	Very slow infiltration rate indicates soil absorbs water very slowly, and runoff and ponding will occur. ☐
Compaction/Root growth	Wire flag enters soil easily to a depth below the topsoil layer; unrestricted root penetration. ☐	Wire flag enters soil, but requires force to reach a depth below the top soil layer; root growth restricted. ☐	Wire flag enters soil with force, but does not penetrate through the top soil layer; roots growing laterally. ☐
Organic Matter (Visual or Munsell book)	Soil is dark brown or black in color; organic matter is visible in the topsoil layer. Value ≤ 3 and chroma ≤ 3 . ☐	Soil is somewhat dark in color; little organic matter is visible in the topsoil layer. Value = 4 and chroma = 4 ☐	Soil is bright to dull colored; no organic matter is visible in the topsoil layer. Value > 4 and chroma > 4 ☐
Soil Structure/Aggregation	Soil is granular, soft and crumbly, held together with many fine roots. Looks like cottage cheese. ☐	Soil is blocky and firmer with some fine roots. ☐	Soil is single grain, massive or platy and hard to break apart. It has few or no fine roots. ☐
Earthworms and Macroinvertebrates	Earthworms/grubs etc. >3 per spade, obvious middens, many pores and casts. ☐	Earthworms/grubs etc. 1 to 3 per spade, few middens, few pores and casts. ☐	Earthworms/grubs etc. None present per spade, no middens, pores or casts. ☐
Soil Odor	Earthy/Sweet odor ☐	Little odor at all ☐	No odor at all or sour, metallic, kitchen sink, rotten egg ☐

Data from recent soil pH and/or organic matter analysis (if available): _____

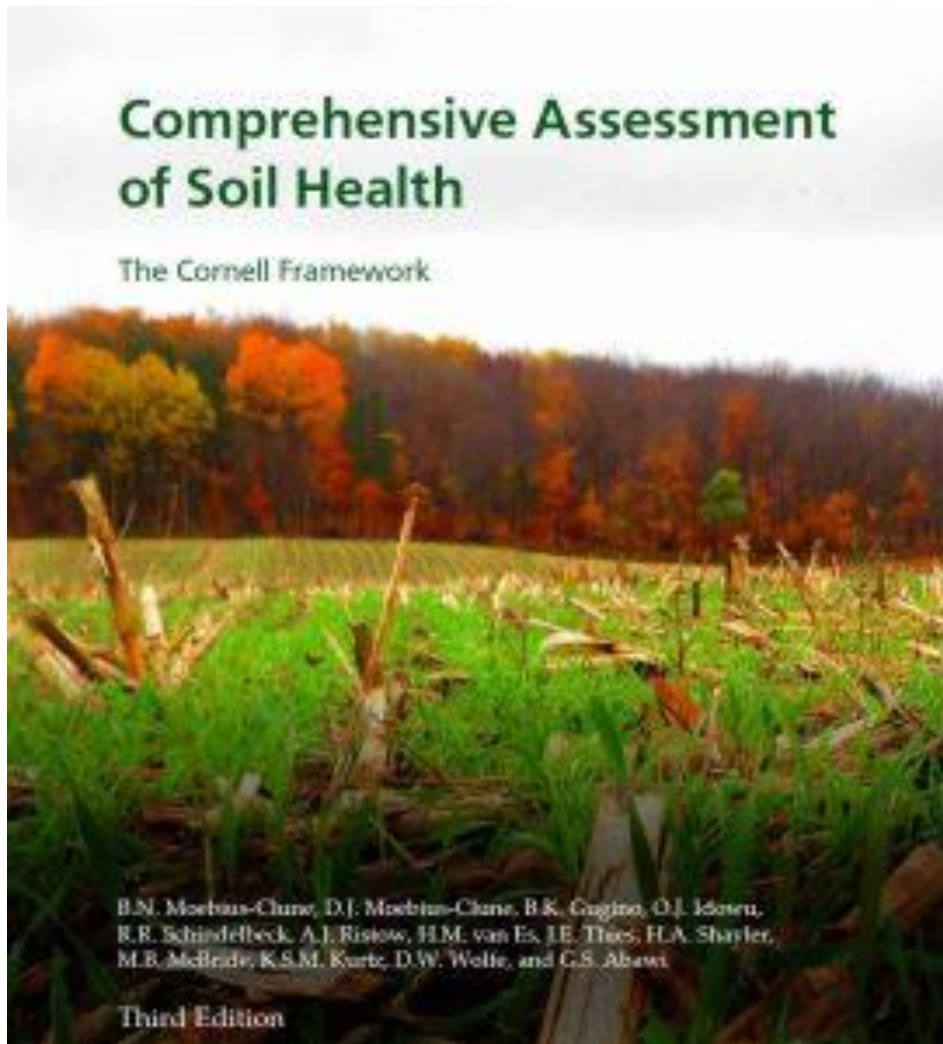
youtube.com/watch?v=GE2QWaPQ7Sk



Soil residue cover, color/OM, structure, odor, infiltration, compaction, earthworms

Laboratory evaluation

Comprehensive Assessment of Soil Health (CASH)



Analyze an array of soil properties

- Surface/subsurface hardness
- Wet aggregate stability
- Organic matter content
- Active carbon content
- Available water capacity
- ACE protein index Autoclaved citrate extractable
- Soil respiration rate
- Soil pH
- Extractable P & K
- Extractable minor nutrients

Calculate a SH score

Recommend BMPs

Comprehensive Assessment of Soil Health

From the Cornell Soil Health Laboratory, Department of Soil and Crop Sciences, School of Integrative Plant Science, Cornell University, Ithaca, NY 14853. <http://soilhealth.cals.cornell.edu>



Grower:
Mr. T Organic Grains
556 Loamy Haven
Hardwork, PA 12435

Sample ID: LL6
Field ID: Deep six
Date Sampled: 10/16/2015

Test Report

Measured Soil Textural Class: **sandy loam** Sand: 59% - Silt: 36% - Clay: 5%

Group	Indicator	Value	Rating	Constraints
physical	Available Water Capacity	0.09	28	
physical	Surface Hardness	255	14	Rooting, Water Transmission
physical	Subsurface Hardness	400	18	Subsurface Pan/Deep Compaction, Deep Rooting, Water and Nutrient Access
physical	Aggregate Stability	56.4	76	
biological	Organic Matter	2.1	54	
biological	ACE Soil Protein Index	6.9	44	
biological	Soil Respiration	0.6	55	
biological	Active Carbon	359	32	
chemical	Soil pH	5.9	54	
chemical	Extractable Phosphorus	2.3	66	
chemical	Extractable Potassium	175.3	100	
chemical	Minor Elements Mg: 134.0 / Fe: 3.4 / Mn: 2.7 / Zn: 1.3		100	

Overall Quality Score: **53** / Medium

Soil (health) degradation

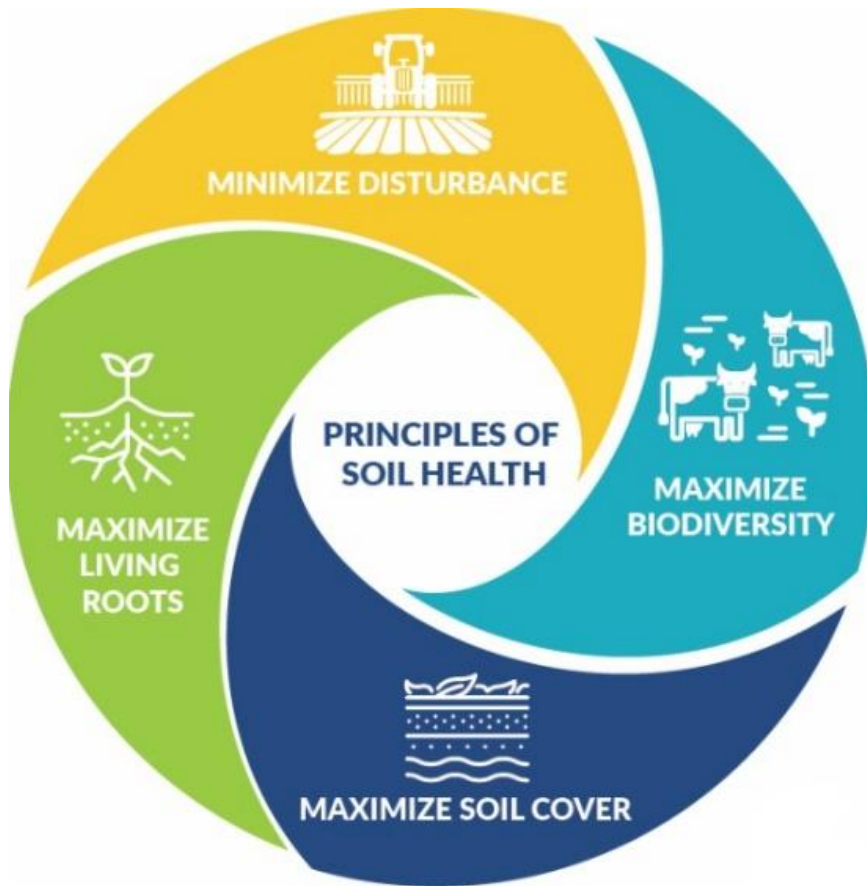
A change in the health status that reduces the capacity of a soil to provide goods and services for its beneficiaries. Degraded soils have a health status such, that they do not provide the normal goods and services of the particular soil in its ecosystem --- FAO

Soil health degradation processes

- Soil erosion
- Organic matter loss
- Acidification
- Salinization
- Compaction
- Soil sealing
- Nutrient depletion
- Nutrient imbalance
- Soil biodiversity loss
- Toxicant accumulation



Soil health principles



- 1) Maximize the soil surface cover with plant biomass
- 2) Minimize soil disturbance
- 3) Diversify plants growing in soil
- 4) Maintain living roots in soil as often as possible
- 5) Integrate livestock, water, & nutrient management in SH manag.

Soil health management practices



- 1) Proper land use
- 2) Crop rotation
- 3) Conservation tillage
- 4) Cover crops
- 5) Organic fertilization
- 6) Livestock integration

...

“For each 1% of U.S. cropland adopting an adaptive soil health system, annual economic benefits would translate into \$226 million of societal value through increased WHC, reduced erosion & nutrient loss, and reduced GHG emissions, as well as \$37 million of on-farm value through greater productivity.” - The Nature Conservancy (2016)

Crop rotation

Two or more crops alternating on the same land at different time

Corn – soybean

Corn – soybean – winter wheat

Winter wheat – rice – canola – peanut

...

Benefits of a good crop rotation:

- a. Help with insect and disease control**
- b. Increase yields**
- c. Mitigate weed pressure**
- d. Maintain or improve soil structure**
- e. Reduce soil erosion and runoff risks**
- f. Increase soil fertility if legume crops are used**

Conservation tillage

Any reduced tillage or planting system in which $\geq 30\%$ of the soil surface is covered by crop residues after planting.



Benefits

- 1) Reduce soil erosion
- 2) Reduce subsurface soil compaction
- 3) Improve soil structure
- 4) Improve soil organic matter
- 5) Enhance soil biology
- 6) Improve water infiltration
- 7) Conserve soil water
- 8) Reduce machinery maintenance cost

Soil health differences by no-till and conventional tillage



Cover crops

Crops growing on fallow lands to control soil erosion



Cover crop vs. cash crop

Functions of cover crops:

- a. reduce soil erosion
- b. add organic matter
- c. reduce weeds & suppress pests
- d. recycle nutrients and reduce nutrient loss
- e. reduce compaction and improve soil structure
- f. improve soil health & fertility
- g. $\uparrow$ H₂O infiltration & $\downarrow$ evaporation
- h. serve as emergency forage

Soil organic inputs

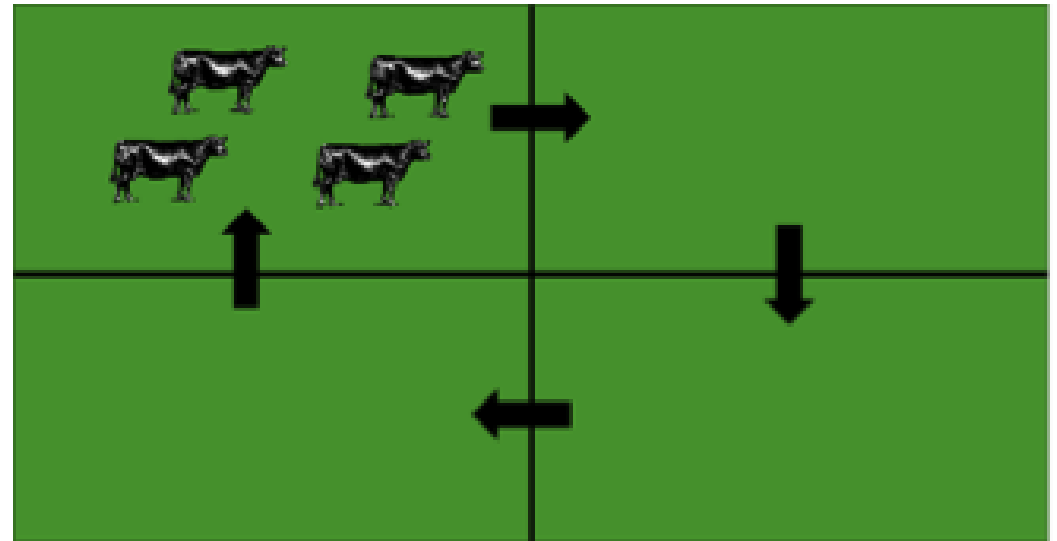


Crop residues
Green manure plants
Compost
Animal manure
Biosolids
Biochar
...

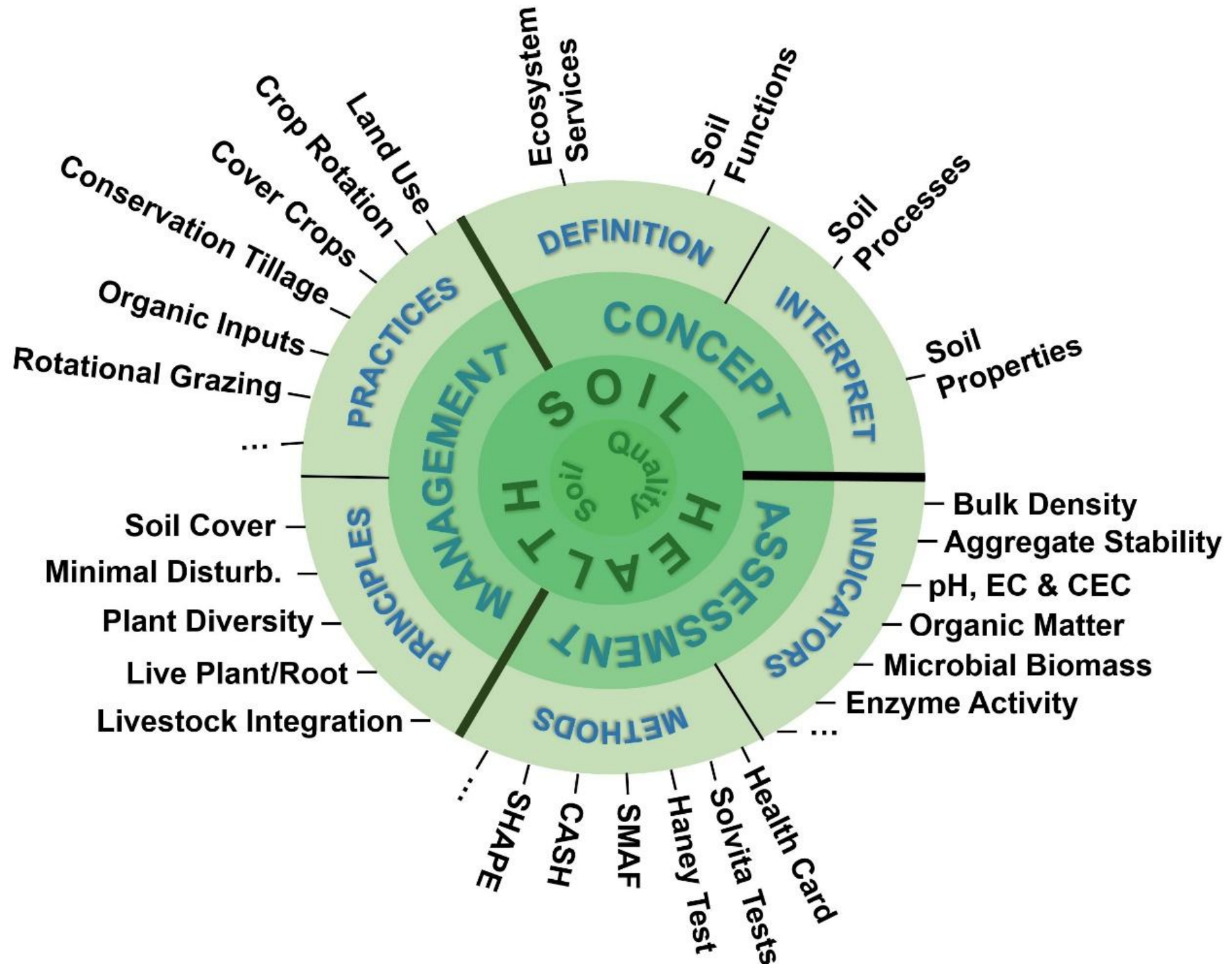
Benefits of soil organic matter improvement

- **Enhancement of soil health, biodiversity, & microbial activity**
- **Increase in soil ecosystem resilience**
- **Off-farm water quality improvement**
- **Climate change mitigation**

Crop-range-livestock integration and rotational grazing



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Review

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Abstract: In the past decade soil health has been intensively studied as a science and practiced as a means to help improve the global social, envi-

..... Overall, the recommended soil health indicators and assessment methods need further validation and improvement in relevance, scientific validity, practicality, and local adaptation. Continuous research, education, and outreach efforts are warranted to promote localized development, adoption, and implementation of soil health assessment and management.

Keywords: soil health indicators; comprehensive assessment; cover crop; conservation tillage; rotational grazing

A healthy soil is the foundation of sustainable agriculture



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