Soil Quality

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Agenda

- Introduction to soil
- Introduction to soil quality
- Assessing soil quality
- Current limitations
- Additional Resources

What is Soil?

- ***What is your definition of soil?***

- Soil Science Society of America:
  - The layer(s) of generally loose mineral and/or organic material that are affected by physical, chemical, and/or biological processes at or near the planetary surface and usually hold liquids, gases, and biota and support plants.

Soils are Diverse

- Many different types of soils around the globe
- Soils differ by
  - Physical properties
    - Examples: color, density, porosity, texture
  - Chemical properties
    - Example: pH
  - Fertility
    - Example: phosphorus content
  - Biology
    - Example: microbial communities
  - Mineralogy
    - Example: kaolinite versus smectite

Pedogenic Processes

- Four pedogenic processes that act on any given soil
- Soil eventually differentiates from the original parent material
- Four pedogenic processes:
  - Transformations
  - Translocations
  - Additions
  - Losses

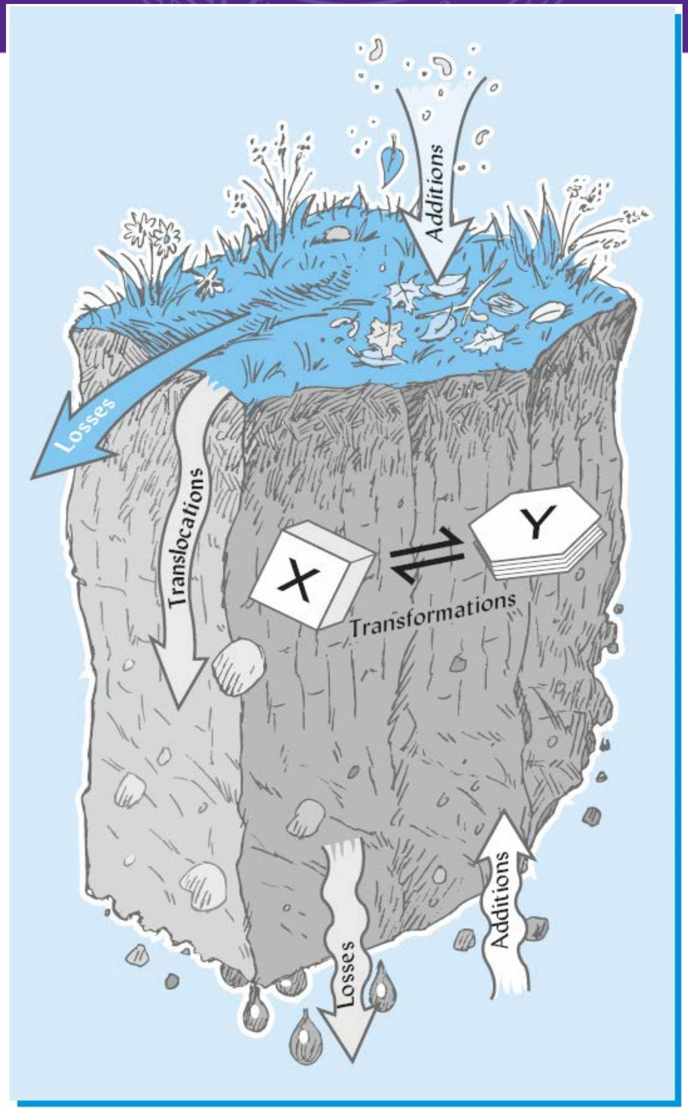


Figure 2.24 from Brady and Weil (2010)

The Five Soil Forming Factors

- Soil profiles are a function of 5 soil forming factors
- Soil = *f(CL, O, R, P, T)*

  ***CL**imate*

  ***O**rganisms (biota)*

  ***R**elief (topography)*

  ***P**arent material*

  ***T**ime*

Soil and the "Pedosphere"

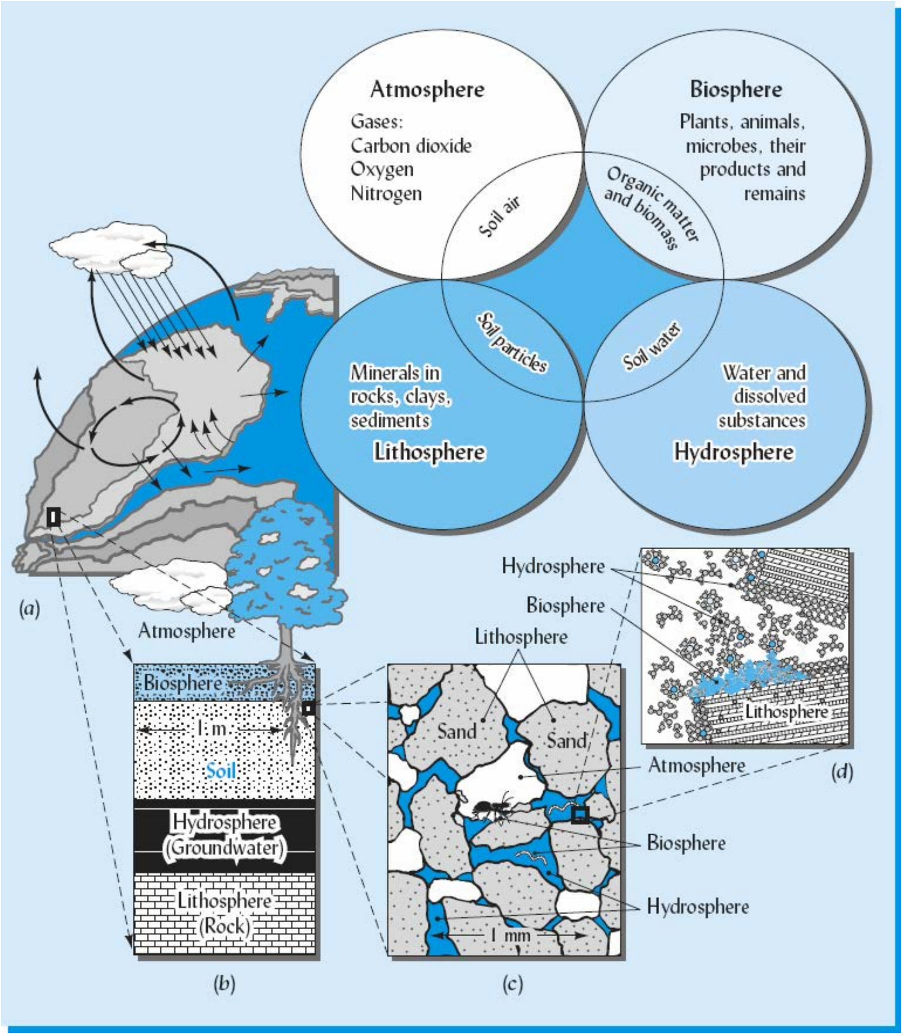


Figure 1.8 from Brady & Weil (2010)

The "pedosphere" is the interface between:

- Atmosphere (air)
- Biosphere (living things)
- Hydrosphere (water)
- Lithosphere (rock)

What is “Soil Quality”?

- ***How do you define soil quality?***

- “The capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.” (SSSA Glossary of Soil Science Terms, 2018)
- “… a measure of how well a soil fulfills either its intrinsic role in the biosphere, or its role as defined by the needs of human society.” (Chesworth, 2008)

Soil Quality & Soil Health

- Soil Quality ≅ Soil Health
  - Terms often used interchangeably
- Human analogy: health versus fitness
- Soil quality emphasizes function
- Soil quality also emphasizes human use

Functions of Soil

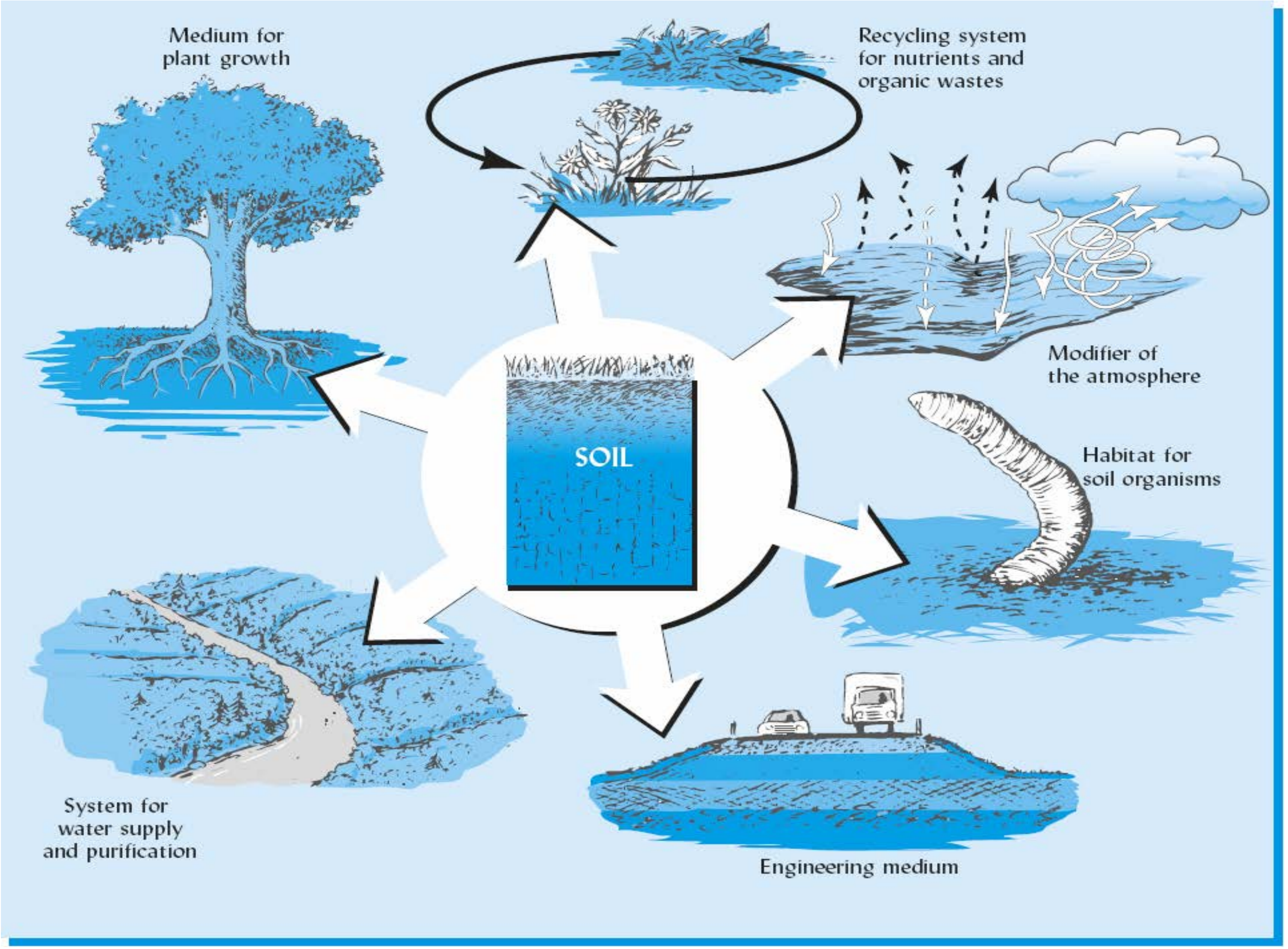


Figure 1.2 from Brady & Weil (2010)

Soil as a Media for Plant Growth

- Soils provide plants:
  - Physical support
  - Air
  - Water
  - Temperature moderation
  - Protection from toxins
  - Nutrient elements

Wikipedia Commons, by Arlington County

Soils Provide Nutrients to Plants

Table 1.1

ELEMENTS ESSENTIAL FOR PLANT GROWTH AND THEIR SOURCES[a]

The chemical forms most commonly taken in by plants are shown in parentheses, with the chemical symbol for the element in bold type.

Macronutrients: Used in relatively large amounts (>0.1% of dry plant tissue)		Micronutrients: Used in relatively small amounts (<0.1% of dry plant tissue)
Mostly from air and water	Mostly from soil solids	From soil solids
Carbon (**C**O_2) Hydrogen (**H**$_2O$) Oxygen (**O**$_2$, H_2**O**)	*Cations:* Calcium (**Ca**$^{2+}$) Magnesium (**Mg**$^{2+}$) Nitrogen (**N**H_4^+) Potassium (**K**$^+$) *Anions:* Nitrogen (**N**O_3^-) Phosphorus (H_2**P**O_4^-, H**P**O_4^{2-}) Sulfur (**S**O_4^{2-})	*Cations:* Copper (**Cu**$^{2+}$) Iron (**Fe**$^{2+}$) Manganese (**Mn**$^{2+}$) Nickel (**Ni**$^{2+}$) Zinc (**Zn**$^{2+}$) *Anions:* Boron (H_3**B**O_3, H_4**B**O_4^-) Chlorine (**Cl**$^-$) Molybdenum (**Mo**O_4^{2-})

[a] Many other elements are taken up from soils by plants but are not *essential* for plant growth (see Epstein and Bloom, 2005).

Table 1.1 from Brady & Weil (2010)

Soil as a Regulator of Water

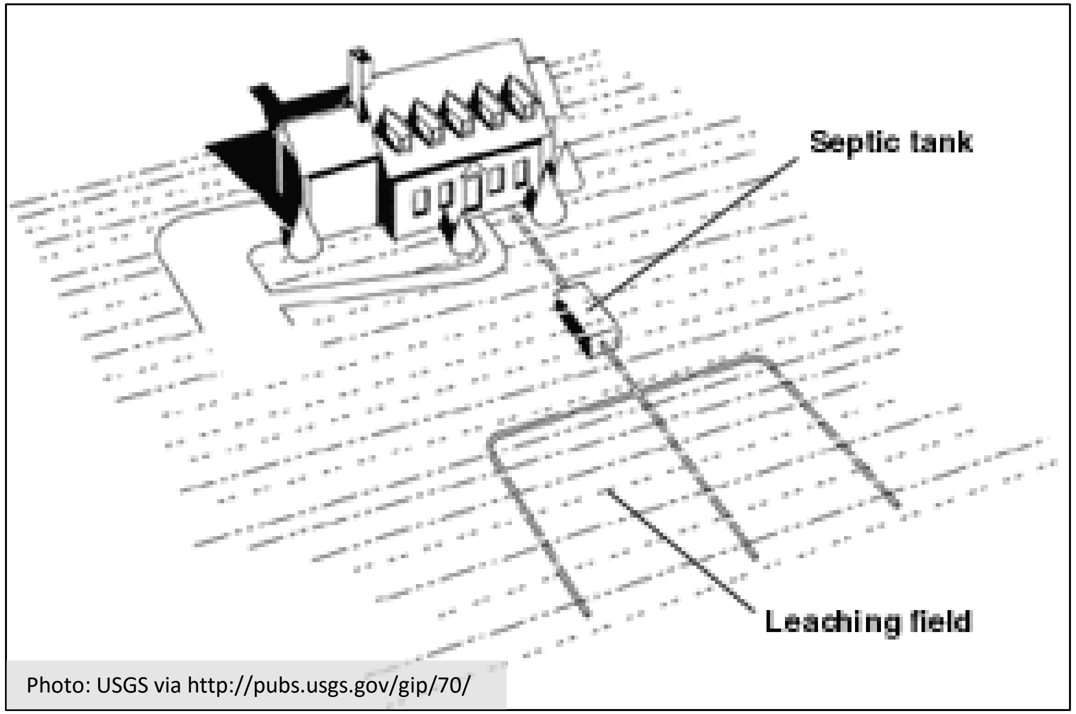
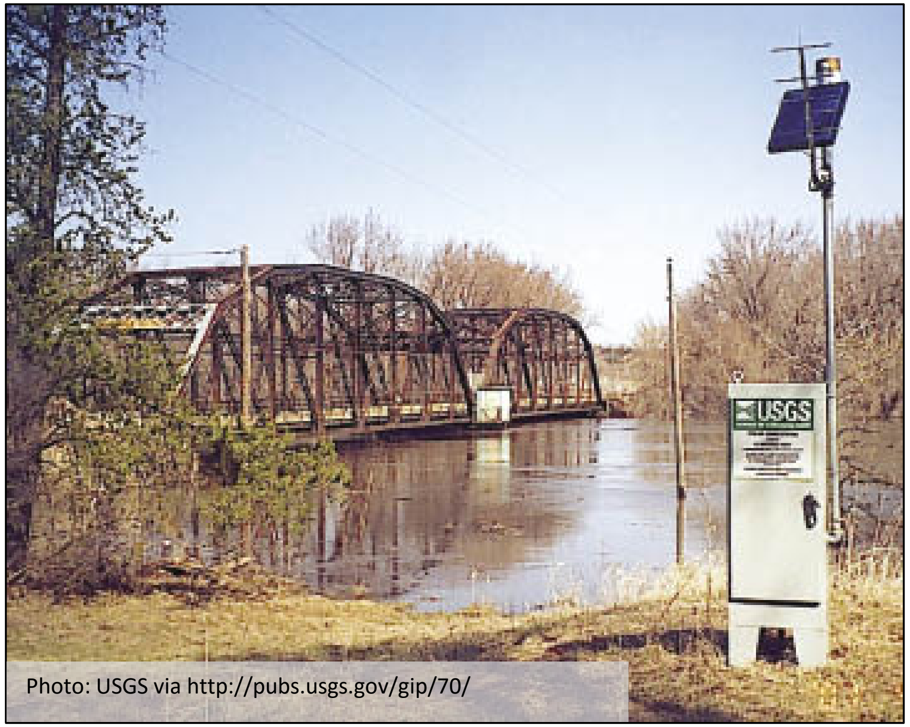


Photo: USGS via http://pubs.usgs.gov/gip/70/

Soil as a Regulator of Water



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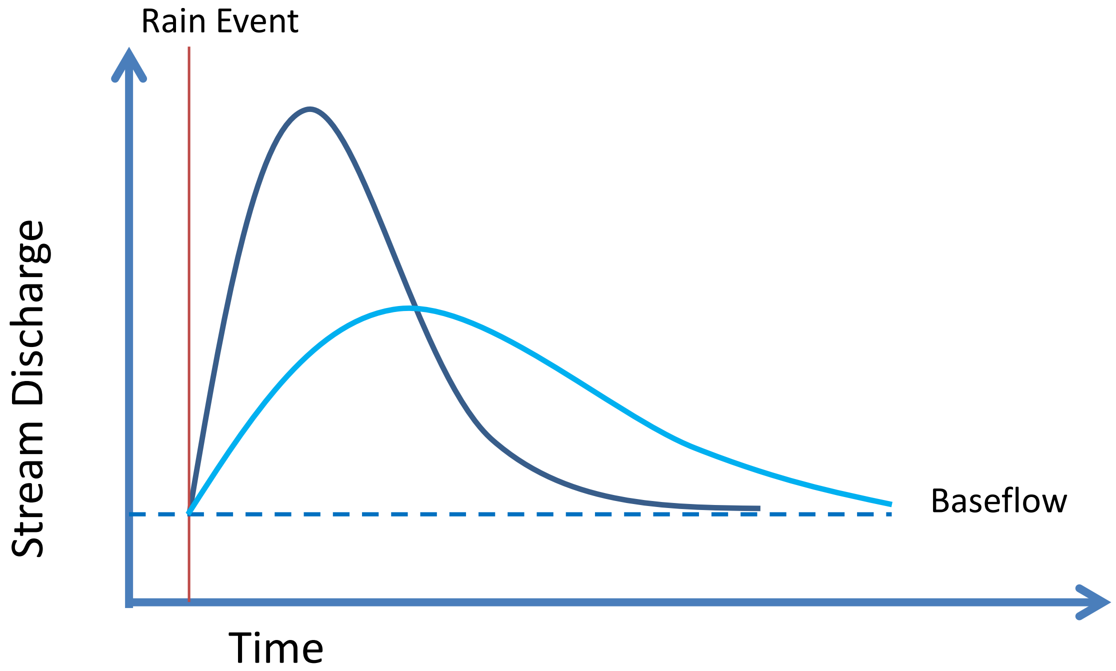


Soil as a Recycler of Raw Materials

"Mycena inclinata, Clustered Bonnet, UK" by Stu's Images. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Mycena_inclinata,_Clustered_Bonnet,_UK.jpg#mediaviewer/File:Mycena_inclinata,_Clustered_Bonnet,_UK.jpg

Soil as a Modifier of the Atmosphere

NOAA George E. Marsh Album via Wikipedia Commons,
http://commons.wikimedia.org/wiki/File:Dust-storm-Texas-1935.png

Subsidence near the Everglades.
Photo: Mike Vepraskas

Soil as Habitat

Gopher tortoise, Wikipedia Commons,
http://commons.wikimedia.org/wiki/File:Gopher_tortoise_entering_burrow.JPG

Centipede, Wikipedia Commons,
http://commons.wikimedia.org/wiki/File:Centipede.jpg

Soil as an Engineering Medium


By Saffron Blaze - CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=29651325


By Lisa Demer, Alaska Dispatch News, https://www.adn.com/alaska-news/rural-alaska/2017/07/07/the-permafrost-is-dying-bethel-sees-increased-shifting-of-roads-and-buildings/

Functions of Soil

- Soil quality is relative
- Soil quality depends on the desired function

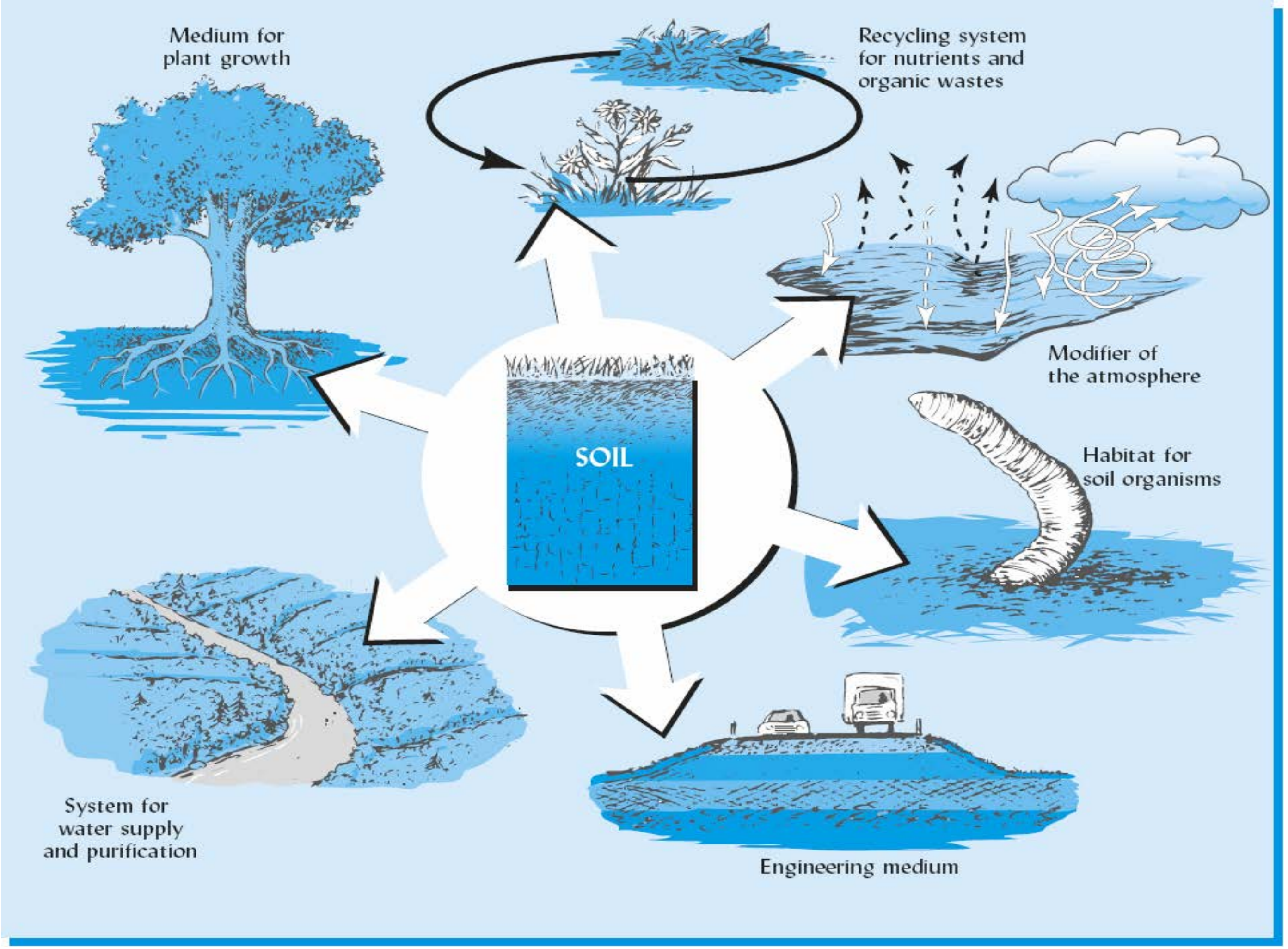


Figure 1.2 from Brady & Weil (2010)

Assessing Soil Quality

- Cannot be determined by a single measure
  - Example: organic matter

Assessing Soil Quality

- Cannot be measured directly
- Use multiple indicators to make inferences on soil quality
  - Physical
  - Chemical
  - Biological
- Can include both field observations and lab analyses

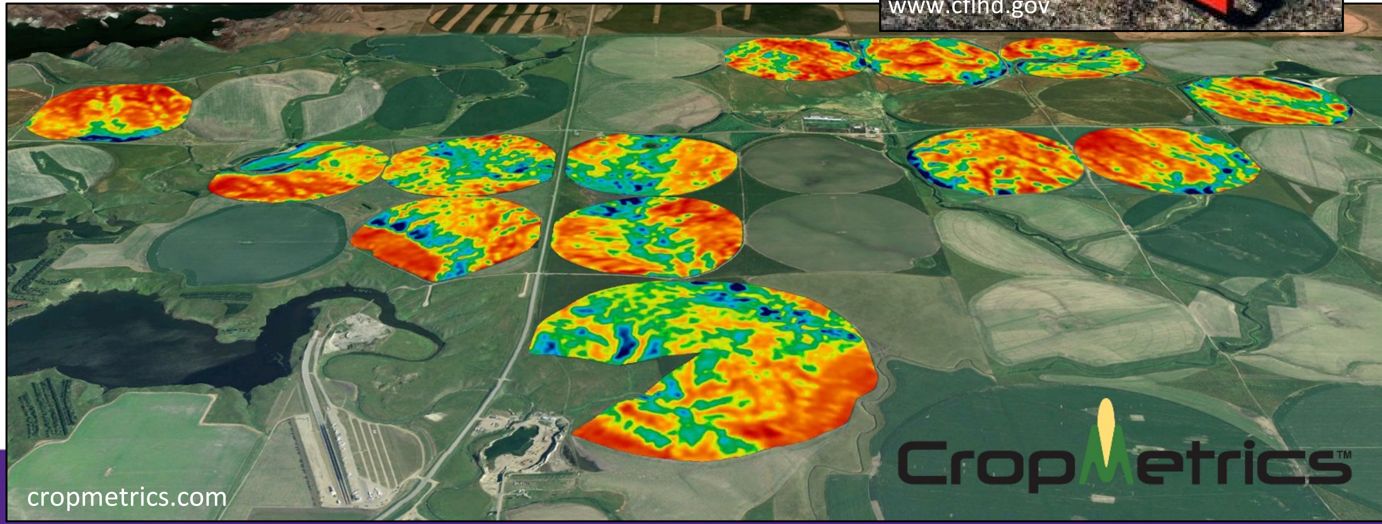
Example Physical Indicators

- Aggregate stability, slaking
- Available water holding capacity
- Surface hardness
- Subsurface hardness
- Infiltration

Example Chemical Indicators

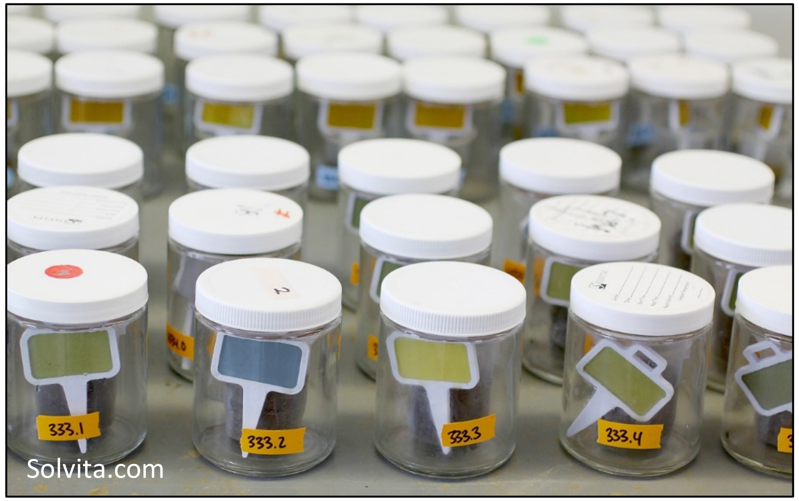
- Soil pH
- Buffer capacity
- Extractable nutrients
- Extractable heavy metals
- Sodicity
- Salinity or electrical conductivity



Example Biological Indicators

- Respiration
- Organic carbon
- Active carbon
- Potentially mineralizable nitrogen
- Root health rating
- Earthworm counts
- Crop yield or plant productivity
- Plant tissue tests



Measuring and Monitoring Soil Quality

Steps

1. Choose several indicators for each category
   - Physical
   - Chemical
   - Biological
2. Develop target values for each indicator
3. Measure soil under current conditions
4. Develop management plan to achieve target indicator value
5. Conduct assessment on regular basis

Considerations

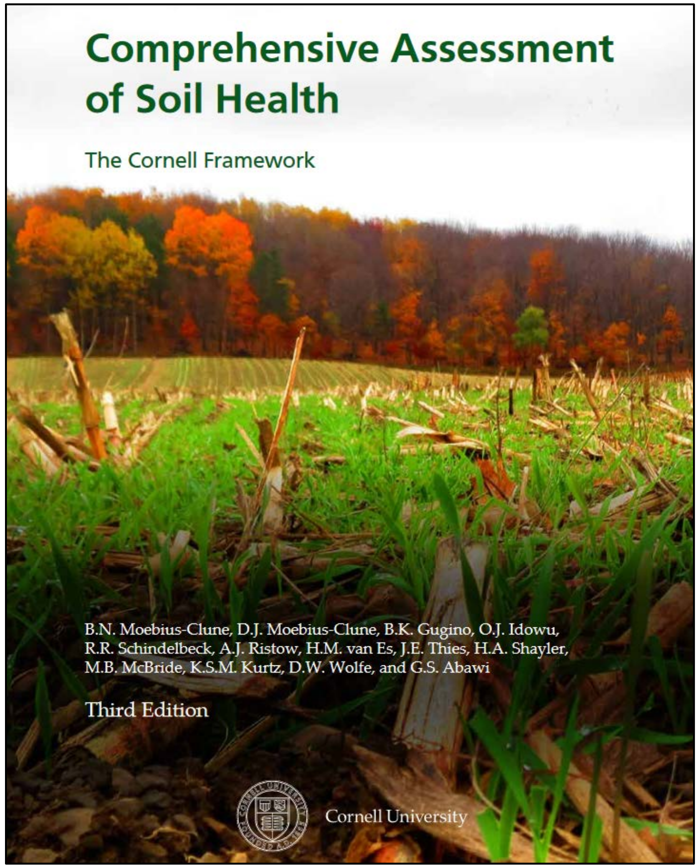
- Indicators should be relevant for intended function
- Target values should be realistic for the specific soil
- Sampling and measurements should be conducted to limit sampling bias
  - Size of sample
  - Collected at similar times of year
  - Collected under consistent soil water content
  - Etc.

Soil Quality Measurement Considerations Example: Hardness

- Surface and subsurface hardness measured with a penetrometer
- ***What do you think would cause variability?***
- Variability from:
  - User
  - Soil moisture
  - Cone size
  - Location
  - Time of year

Measurement & Monitoring Example

- The Cornell Framework for Comprehensive Assessment of Soil Health
  - In-field health assessment
  - Lab-based "Comprehensive Assessment of Soil Health" (CASH)



Moebius-Clune et al., 2016, http://soilhealth.cals.cornell.edu/training-manual/

In-field Soil Health Assessment

Indicator Table

Indicator	Poor	Medium	Good
Earthworms	0-1 worms in shovelful of top foot of soil. No casts or holes.	2-10 in shovelful. Few casts, holes, or worms.	10+ in top foot of soil. Lots of casts and holes in tilled clods. Birds behind tillage.
Organic Matter Color	Topsoil color similar to subsoil color.	Surface color closer to subsoil color.	Topsoil clearly defined, darker than subsoil.
Organic Matter Roots/Residue	No visible residue or roots.	Some residue, few roots.	Noticeable roots and residue.
Subsurface Compaction	Wire breaks or bends when inserting flag.	Have to push hard, need fist to push flag in.	Flag goes in easily with fingers to twice the depth of plow layer.
Soil Tilth Mellowness Friability	Looks dead. Like brick or concrete, cloddy. Either blows apart or hard to pull drill through.	Somewhat cloddy, balls up, rough pulling seedbed	Soil crumbles well, can slice through, like cutting butter. Spongy when you walk on it.
Erosion	Large gullies over 2 inches deep joined to others, thin or no topsoil, rapid run-off the color of the soil.	Few rills or gullies, gullies up to two inches deep. Some swift runoff, colored water.	No gullies or rills, clear or no runoff.
Water Holding Capacity	Plant stress two days after a good rain.	Water runs out after a week or so.	Holds water for a long period of time without puddling.
Drainage Infiltration	Water lays for a long time, evaporates more than drains, always very wet ground.	Water lays for short period of time, eventually drains.	No ponding, no runoff, water moves through soil steadily. Soil not too wet, not too dry.
Crop Condition (How well it grows)	Problem growing throughout season, poor growth, yellow or purple color.	Fair growth, spots in field different, medium green color.	Normal healthy dark green color, excellent growth all season, across field.
pH	Hard to correct for desired crop.	Easily correctable.	Proper pH for crop.
Nutrient Holding Capacity	Soil tests dropping with more fertilizer applied than crops use.	Little change or slow down trend.	Soil tests trending up in relation to fertilizer applied and crop harvested.

In-field Soil Health Assessment

Assessment Sheet

Date____________ Crop____________________
Farm/Field ID____________________________
Soil Quality Poor Medium Good

INDICATORS	1	2	3	4	5	6	7	8	9
Earthworms									
Organic Matter Color									
Organic Matter Roots/residue									
Subsurface Compaction									
Tilth/Friability Mellowness									
Erosion									
Water Holding Capacity									
Drainage Infiltration									
Crop Condition									
pH									
Nutrient Holding Capacity									
Other (write in)									
Other (write in)									

Assessment Guide

Indicator	Best Assessed
Earthworms	Spring/Fall Good soil moisture
Organic Matter Color	Moist soil
Organic Matter Roots/Residue	Anytime
Subsurface Compaction	Best pre-tillage or post harvest Good soil moisture
Soil Tilth Mellowness Friability	Good soil moisture
Erosion	After heavy rainfall
Water Holding Capacity	After rainfall During growing season
Drainage Infiltration	After rainfall
Crop Condition	Growing season Good soil moisture
pH	Anytime, but at same time of year each time
Nutrient Holding Capacity	Over a five year period, always at same time of year.

Comprehensive Assessment of Soil Health

Physical

- Available water holding capacity
- Surface hardness
- Subsurface hardness
- Aggregate stability

Biological

- Organic matter
- Soil protein
- Soil respiration
- Active Carbon

Chemical

- Soil chemical composition
  - pH
  - Plant nutrients

Complications of Assessing Soil Quality/Health

Roper et al. (2017) is a great example of the limitations of quantifying soil quality/health

- Soils under different long-term management
  - "Organic" vs "chemical"
  - Tillage vs no-till
- Three regions
  - Mountains
  - Piedmont
  - Coastal Plain
- Analyzed soils using:
  - Cornell's CASH
  - Haney Soil Health Test (HSHT)
  - State soil testing lab

Roper et al., 2017

Soil Fertility & Plant Nutrition

Soil Health Indicators Do Not Differentiate among Agronomic Management Systems in North Carolina Soils

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Recent soil tests evaluating "soil health" on a broad scale may not properly consider the intrinsic limitations of soil properties, and have not been assessed in regionally unique soil conditions. To evaluate three soil tests in North Carolina, we used long-term agronomic management trials from three distinct physiographic regions: mountain (22 yr), piedmont (32 yr), and coastal plain (17 yr). Mountain and coastal plain trials included combinations of organic or chemical management with or without tillage; the piedmont trial included nine different tillage treatments. Soil samples were collected and submitted for analysis as recommended by the North Carolina Department of Agriculture and Consumer Services, Haney soil health test (HSHT), and Cornell comprehensive assessment of soil health (CASH). Plant nutrient concentrations varied but were still sufficient for crops. The CASH physical soil indicators, such as surface hardness and aggregate stability, were not statistically different, regardless of tillage intensity or management. Biological soil indicators (e.g., CO_2 respiration) responded differently to management, but this differentiation was inconsistent among locations and tests. Despite many years of conservation management, the CASH results described mountain soils as "low" or "very low" soil health for all but no-till organic management, which received a "medium" score. The HSHT results considered soil from all but moldboard plowing (piedmont) to be in good health. Finally, there was no correlation between soil health tests and crop yields from North Carolina soils. Soil health tests should be calibrated to better differentiate among soil management effects that vary depending on intrinsic soil limitations.

Abbreviations: AWC, available water capacity; CASH, Cornell comprehensive assessment of soil health; CEC, cation exchange capacity; CPDS, chisel plowing and disking in spring; CPF, chisel plowing in fall; CPS, chisel plowing in spring; CTC, conventional tillage chemical; CTO, conventional tillage and organic management; CTX, chisel and disk tillage with no fertilizer or pesticide inputs; DS, disking in spring; HSHT, Haney soil health test; HM, humic matter; LOI, loss on ignition; MPDF, moldboard plowing and disking in fall; MPDS, moldboard plowing and disking in spring; NCDA&CS, North Carolina Department of Agriculture and Consumer Services; NTC, no-till chemical; OM, organic matter; RYE, realistic yield expectation; WEOC, water-extractable organic C; WEON, water extractable organic N.

Complications of Assessing Soil Quality/Health

Results

- Physical soil indicators (surface hardness, aggregate stability) did not differ
- Biological tests (e.g. respiration) responded to management, but depended on location
- CASH rated all mountain soils as "low" or "very low" for all but no-till organic, which was "medium"
- HSHT rated all soils except the piedmont moldboard plow treatment to be in good health
- No correlation between soil health tests and crop yield

Roper et al., 2017

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My Thoughts RE: Assessment

- Science behind soil quality and soil health is not ready for policy decisions
- Comparing quality/health of two soils is (usually) “apples and oranges”
- Use measurements for long term monitoring of management or remediation practices
- Don’t expect miracles

The Soil Health Conversation

- “Soil health” has replace “soil quality” as the trendy buzzword
- Soil Health Institute identified 19 “Tier 1” indicators

Organic carbon	Electrical conductivity	Erosion rating
pH	Nitrogen	Base saturation
Water-stable aggregation	Phosphorus	Bulk density
Crop yield	Potassium	Available water holding capacity
Texture	Carbon mineralization	Infiltration rate
Penetration resistance	Nitrogen mineralization	Micronutrients
Cation exchange capacity		

https://soilhealthinstitute.org/national-soil-health-measurements-accelerate-agricultural-transformation/

Soil Health Assessment Kits

- Commercially available from:
  - Gempler's
- Can also assemble your own kit using the NRCS checklist

Resources

- Cornell Soil Health Assessment Training Manual
  - http://soilhealth.cals.cornell.edu/extension/manual/manual.pdf
- NRCS webpage on soil health
  - http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/
- NRCS recommended soil health assessment tests and test kit
  - http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/assessment/?cid=nrcs142p2_053873

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My Courses at K-State

- AGRON 305 – Soils
  - Introductory soil science course
  - Every spring/fall semester
  - 4 credits
- AGRON 635 – Soil & Water Conservation
  - Every fall semester
  - 3 credits
- AGRON 935 – Topics in Soils: Root & Rhizosphere Analysis
  - Spring of even years
  - 3 credits

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