Healthy Soils – Part 1:
Soil Science for Sustainable Landscapes

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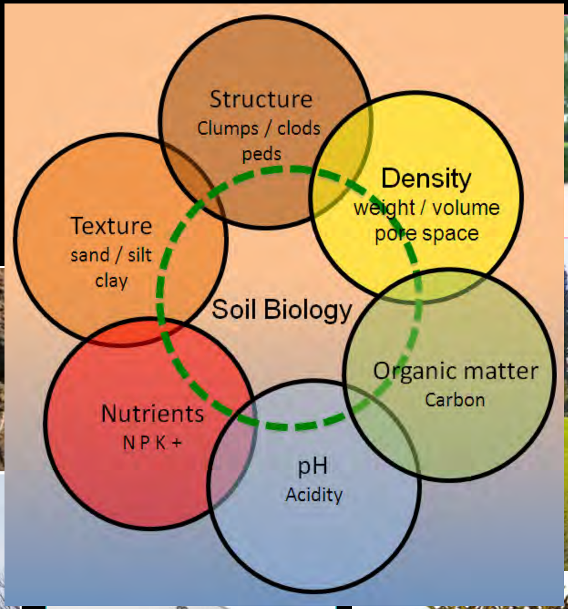
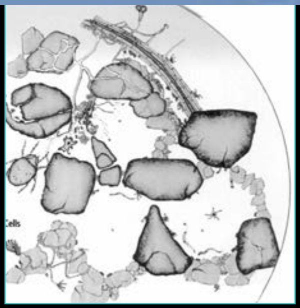
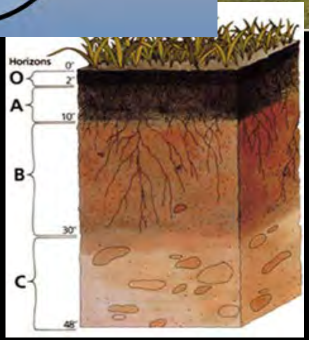
With slides from
James Urban, FASLA, ISA
Urban Tree + Soils







Based on [Healthy Soils Part 1]() and [Healthy Soils Part 2]() by James Urban and David McDonald from ASLA conference Phoenix 9/6/2012, and [Soil Improvement for Stormwater, Erosion, & Landscape Success]() by David McDonald for WSU Low Impact Development. Updated 2/27/2019

www.SoilsforSalmon.org
www.BuildingSoil.org

Protect and Conserve Soil – key ecoPRO BMPs

ecoPRO CERTIFIED SUSTAINABLE LANDSCAPE PROFESSIONAL

DESIGN

1) Identify and map soil characteristics of landscape site
   - ♦Designate soil protection, disturbance, and other construction management areas on a Soil Management Plan

2) Review site grading specifications for accuracy

CONSTRUCTION

1) Use the least invasive construction methods and site sensitive methods
2) Protect tree root zones
3) Reduce import and export of earth materials
4) Amend soil with compost to improve water & nutrient capacity

MAINTENANCE

1) Build healthy soils, with compost, mulch, mulch-mowing etc.
2) Address problem drainage areas with appropriate drainage solutions
3) Create a sustainable plant nutrient management program

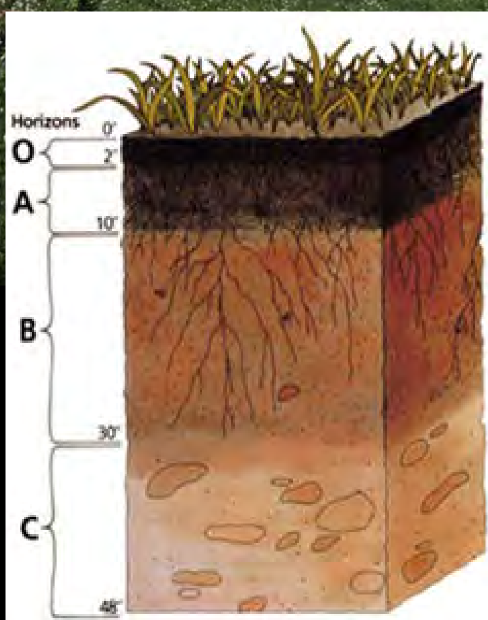
Natural soils vs. Disturbed urban soils

Natural soils

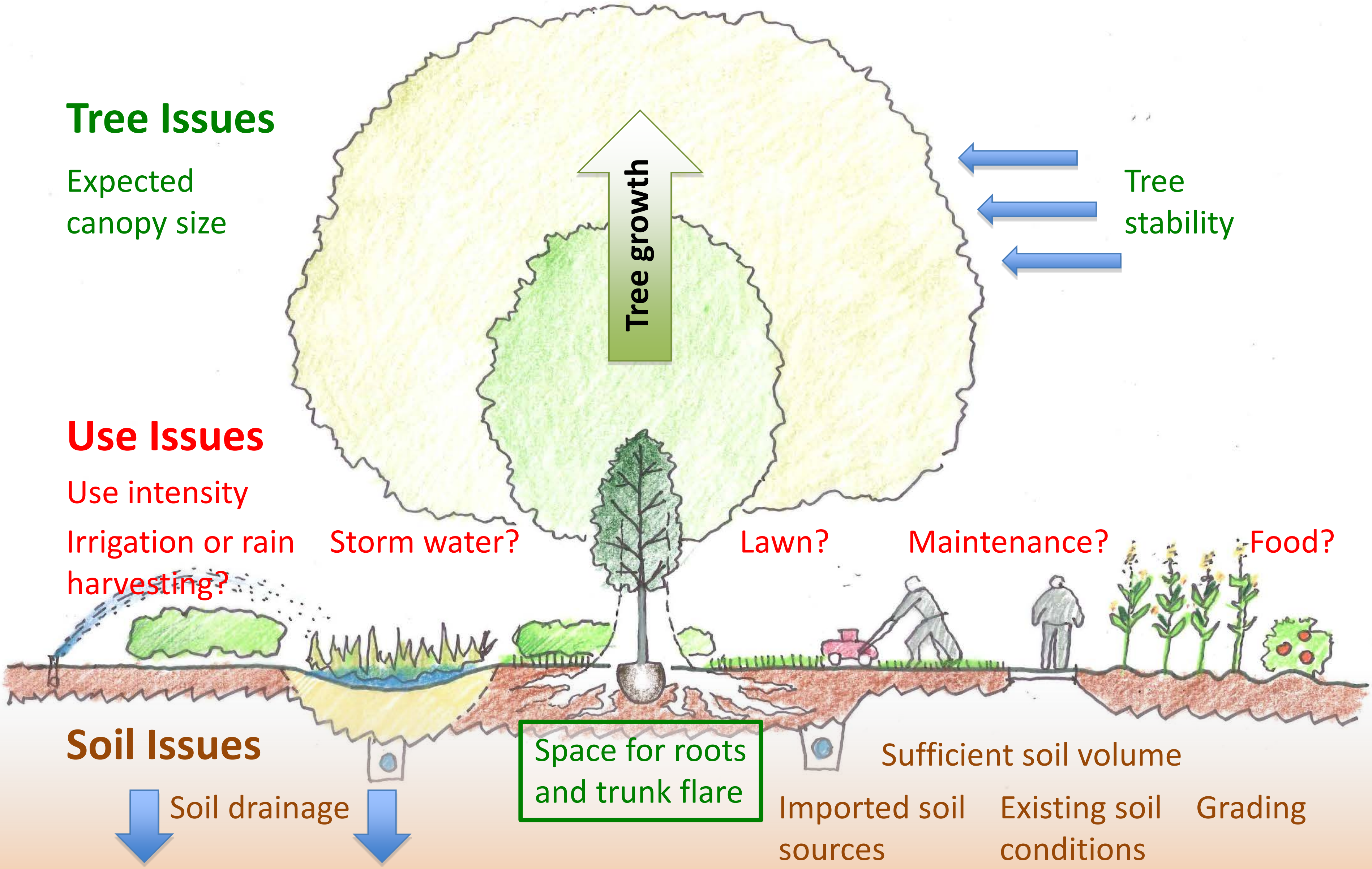
- Uniform across site
- Natural horizons
- Adequate OM, nutrients, structure for native plants

Disturbed urban soils

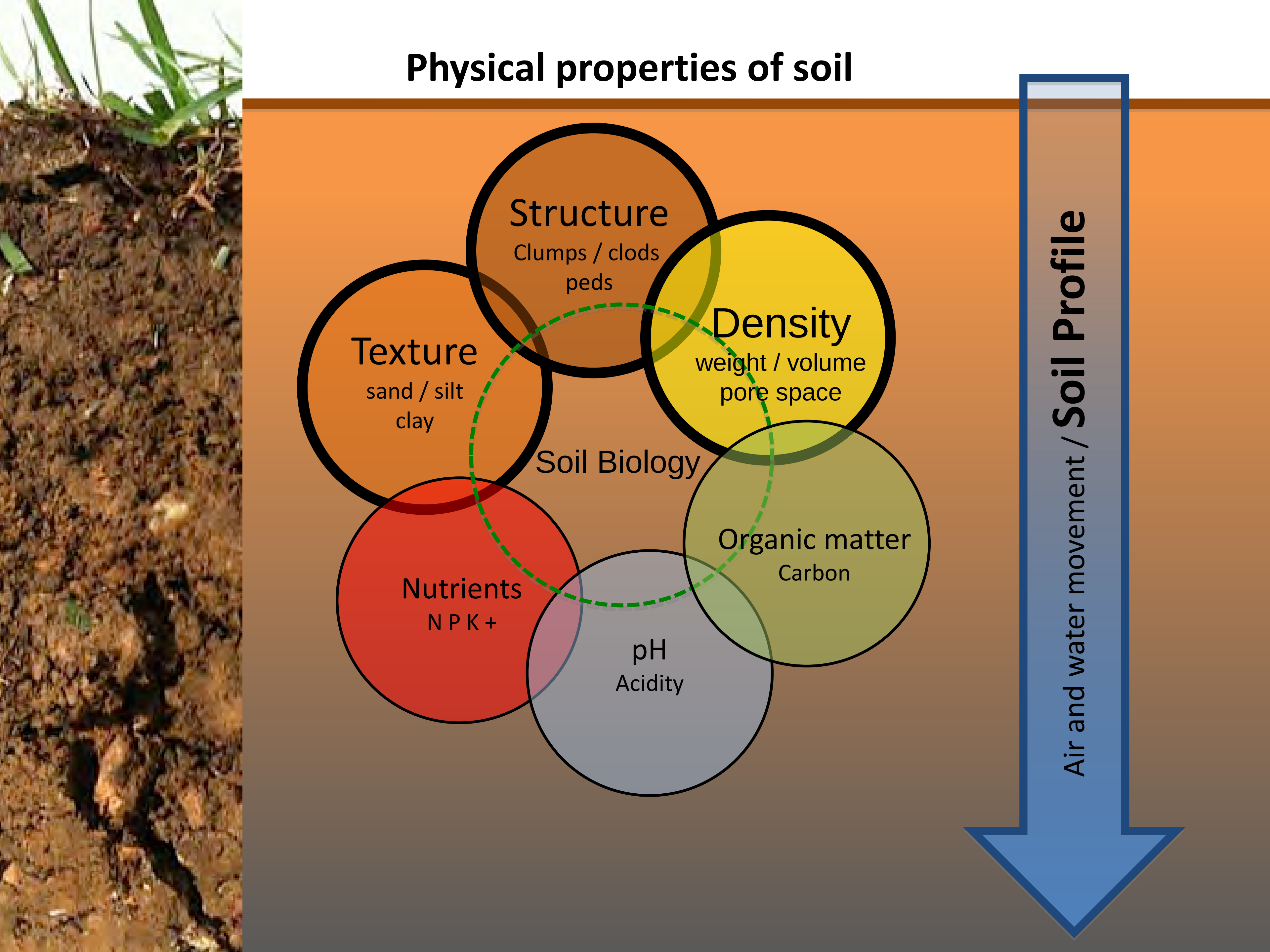
- Vary across site
- Topsoil layer removed
- Compaction, low OM
- Subsoil (or worse) fill layers
- Debris, toxins?



Soil Goals and Requirements



Physical properties of soil



Soil Formation - natural processes

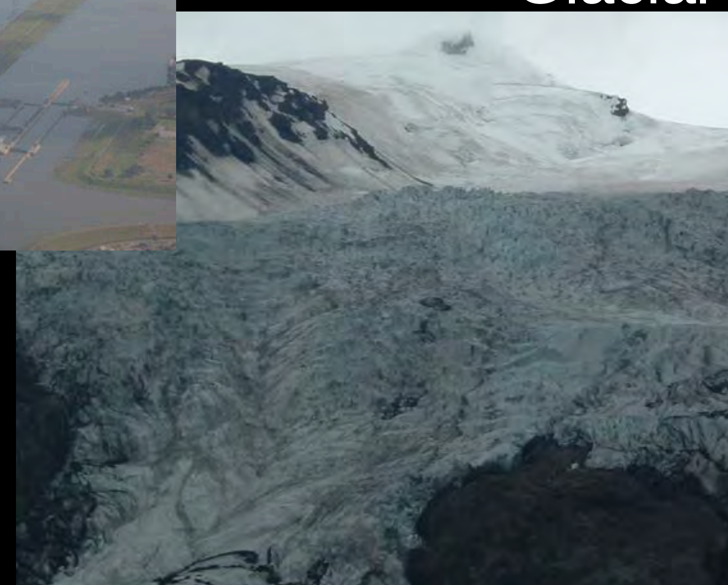
Igneous

Sedimentary

Alluvial

Wind deposited

Glacial



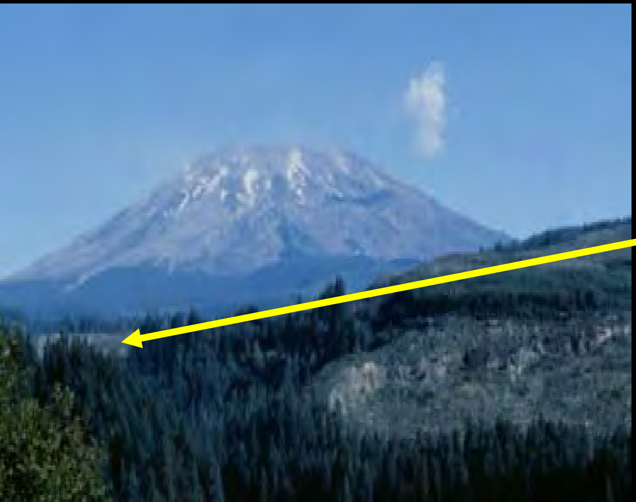
Sub-Soils in the Puget Sound Basin: Leftovers from glaciers & volcanoes

glacial till: unsorted, unstratified mixtures of clay, silt, sand, gravel, and boulders; deposited under ice, or in moraines

hardpan: till compacted under glacier

outwash soils: layers sorted by particle size by water - sand / gravel / rocks

lake/marine bed soils: clay or silt that settled out in lakes & estuaries



volcanic ash: light, fertile, holds moisture - mostly blown east of Cascades

mudflows: mixed size, compact - like till

Learn about Puget Sound soils at:
www.puyallup.wsu.edu/soilmgmt/Soils.html

Glacial till

- May be piled, uncompressed and unsorted, in *moraines* at edge or terminus of glacier

- *Basal till* from under the glacier (1/2 mile of ice over Seattle!) has been compressed into **hardpan**

- Good for foundations, but low permeability and hard for roots to penetrate

Glacial outwash

- May be sorted boulders, gravel
- …sand and fines…..
- Or a mix!

Lake beds, lenses, and layers

- Silts and clays settle out…
- And then may be overlain in lenses with sand or gravel from succeeding outwash
- Grey-yellow color when saturated and anaerobic
- Great for farming, (best nutrient capacity) but unstable in slopes or foundations!

Volcanic ash or mudflows

- *Tephra* (ash) – light, fertile, holds moisture, erodable

- Mudflow – compact, mixed fines and boulders, low permeability, looks and acts like basal till, but more fertile

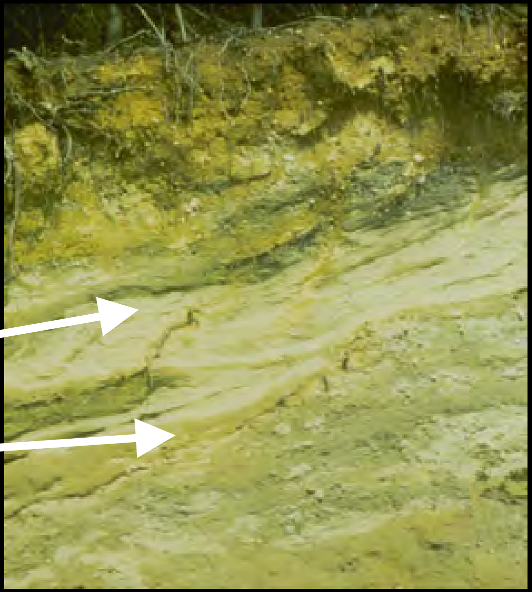
Alluvial soils

- Flat, loamy deposits in river floodplains (or ancient rivers)

- Best for farming, often wasted on development because they're flat

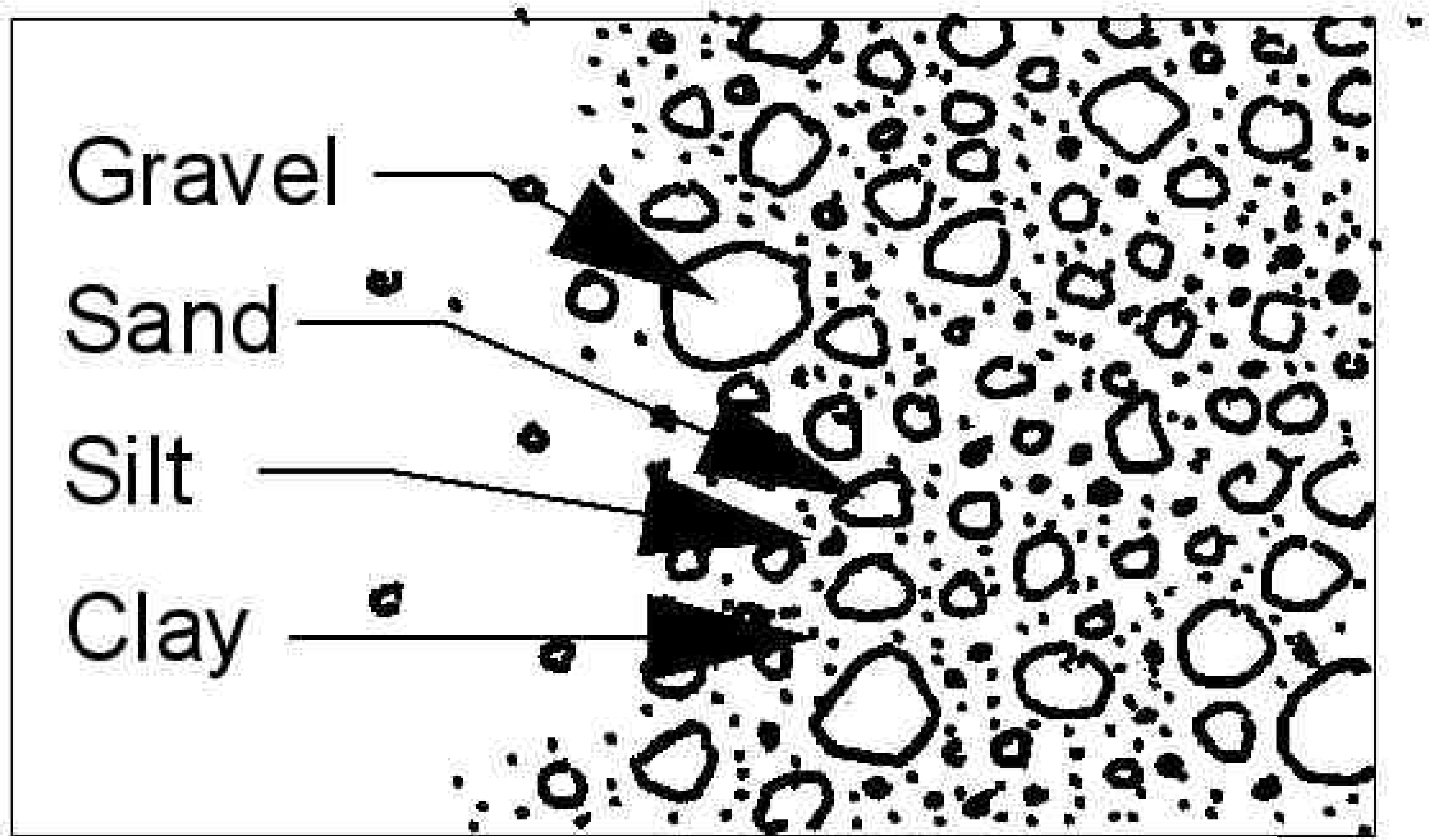
Layers upon layers…
ignore them at your peril!

- Sandy outwash over compacted basal till hardpan
- Thin soil over bedrock
- Clay lenses over hardpan, or inter-layered with sand (unstable!)



Disturbed soils in urban areas

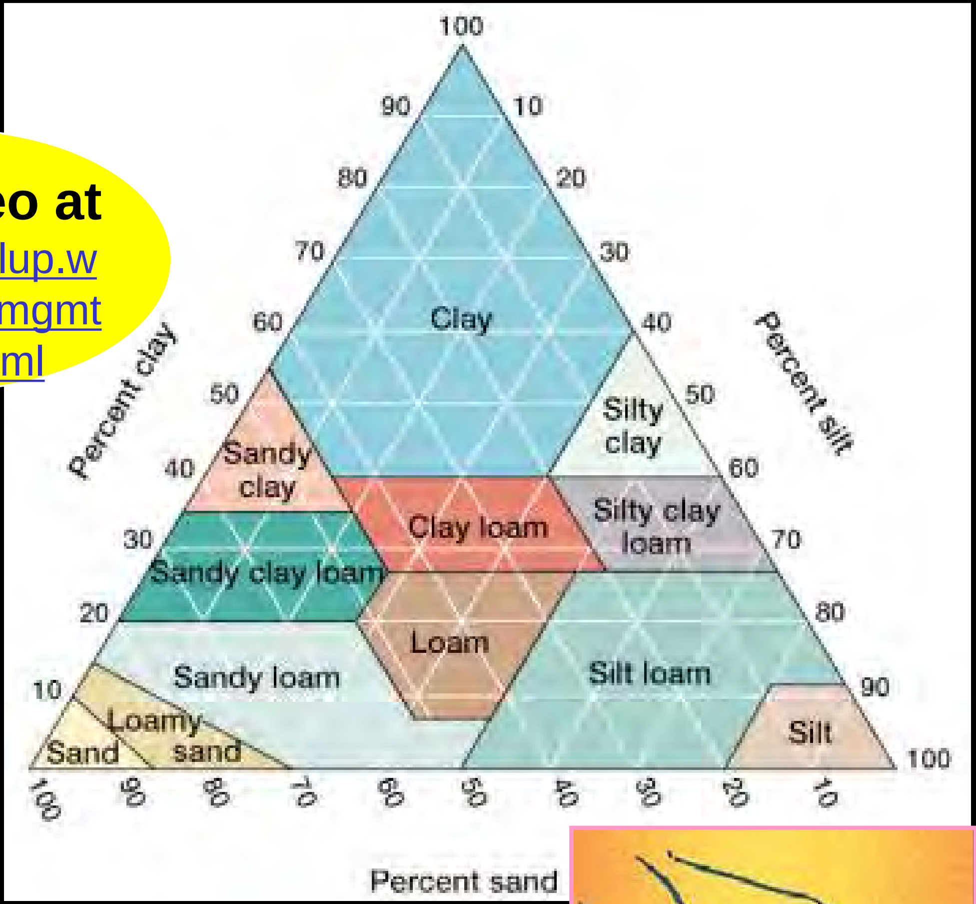
- Topsoil layer removed
- Compaction
- Subsoil (or worse) fill layers.
- Debris or toxins?



Soil Texture (= particle size)

Soil Texture Test

See video at
www.puyallup.wsu.edu/soilmgmt/Soils.html

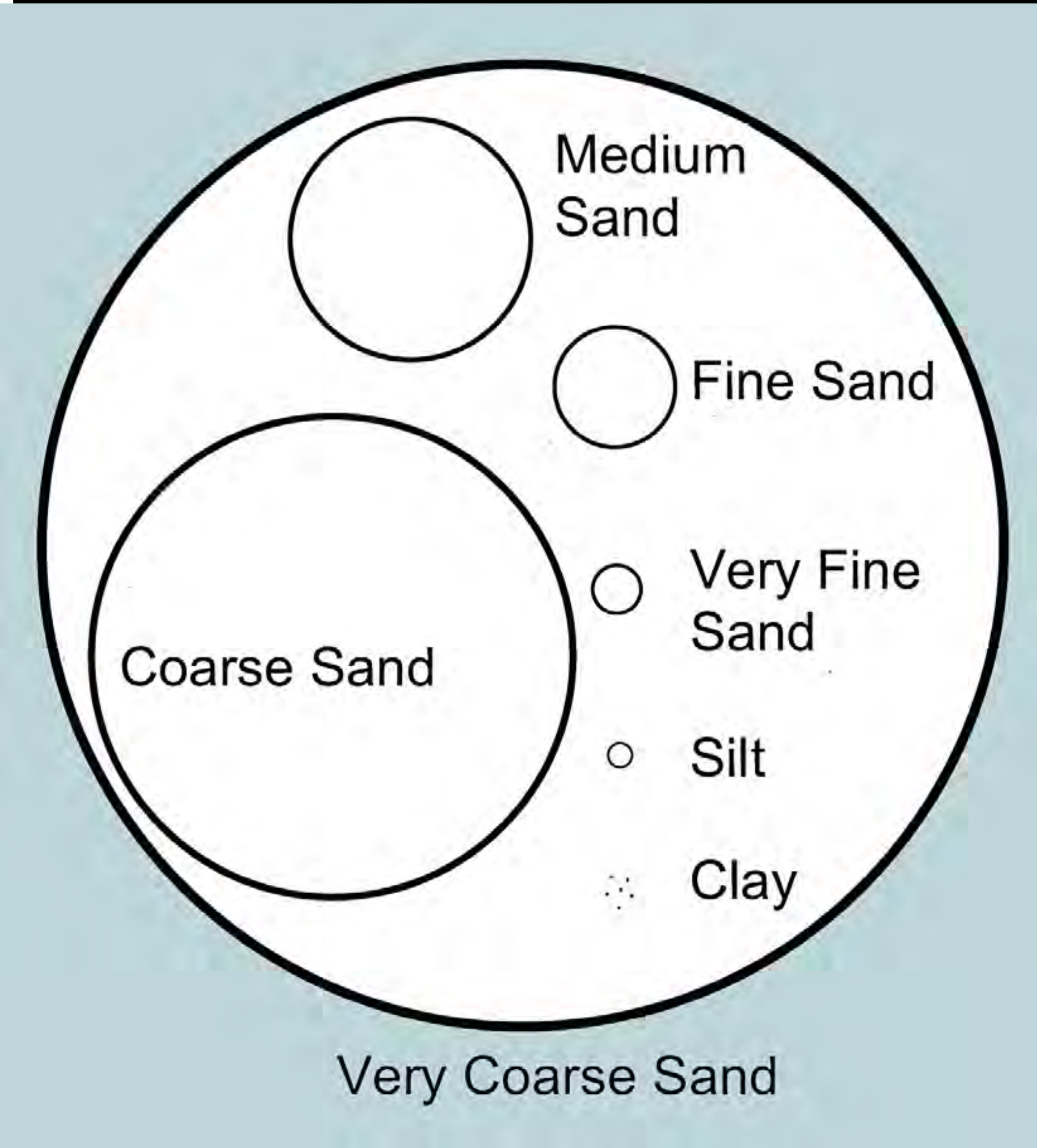


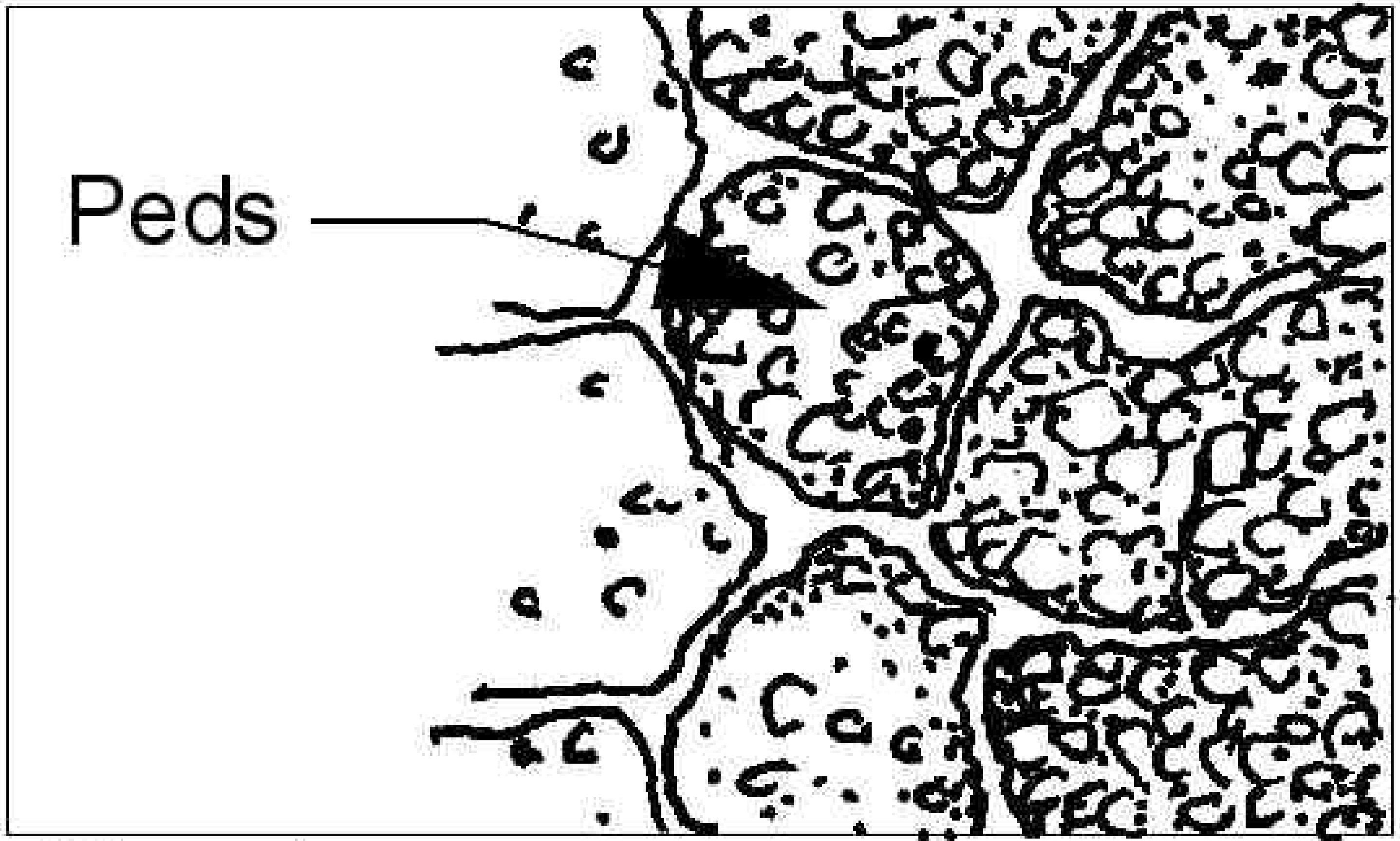
Ribbon+feel test:

Moisten soil, roll between hands, then squeeze out with thumb:

- Sand: no ribbon, grainy
- Sandy loam: ½ inch ribbon
- Loam: thick 1 inch ribbon
- Silt: makes flakes rather than ribbon
- Silty clay loam: thin, breaks easily, has floury feel
- Sandy clay loam: stronger, has grainy feel
- Clay: long (3 inch) ribbon, has smooth feel

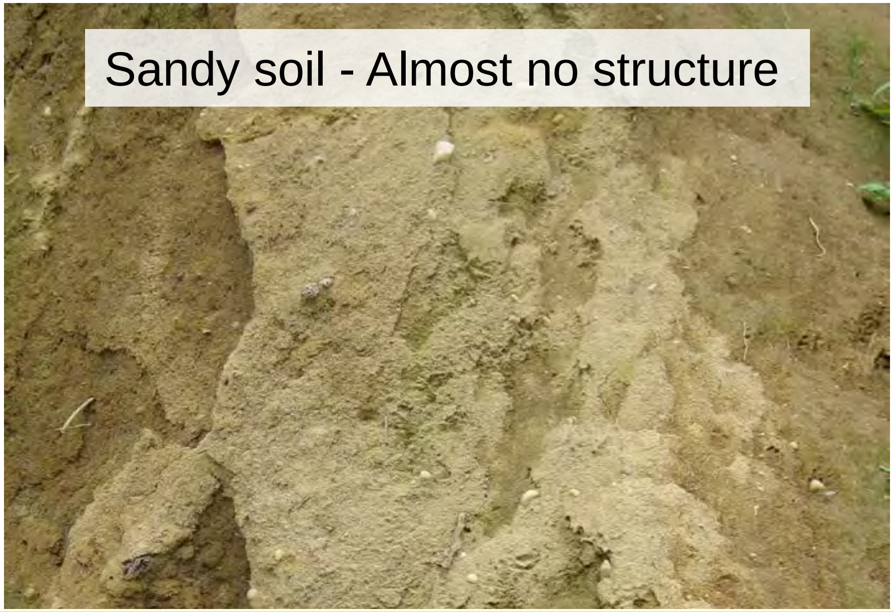
Soil Material	Size (mm)
Clay	<0.002
Silt	0.002 - 0.05
Silt, fine	0.002 - 0.02
Silt, coarse	0.02 - 0.05
Sand	0.05 - 2.00
Very fine sand	0.05 - 0.10
Fine sand	0.10 - 0.25
Medium sand	0.25 - 0.50
Coarse sand	0.50 - 1.00
Very coarse sand	1.00 - 2.00
Gravel	2.0 - 75.0
Cobbles	75.0 - 250.0
Stones	250 - 600
Boulders	> 600





Structure

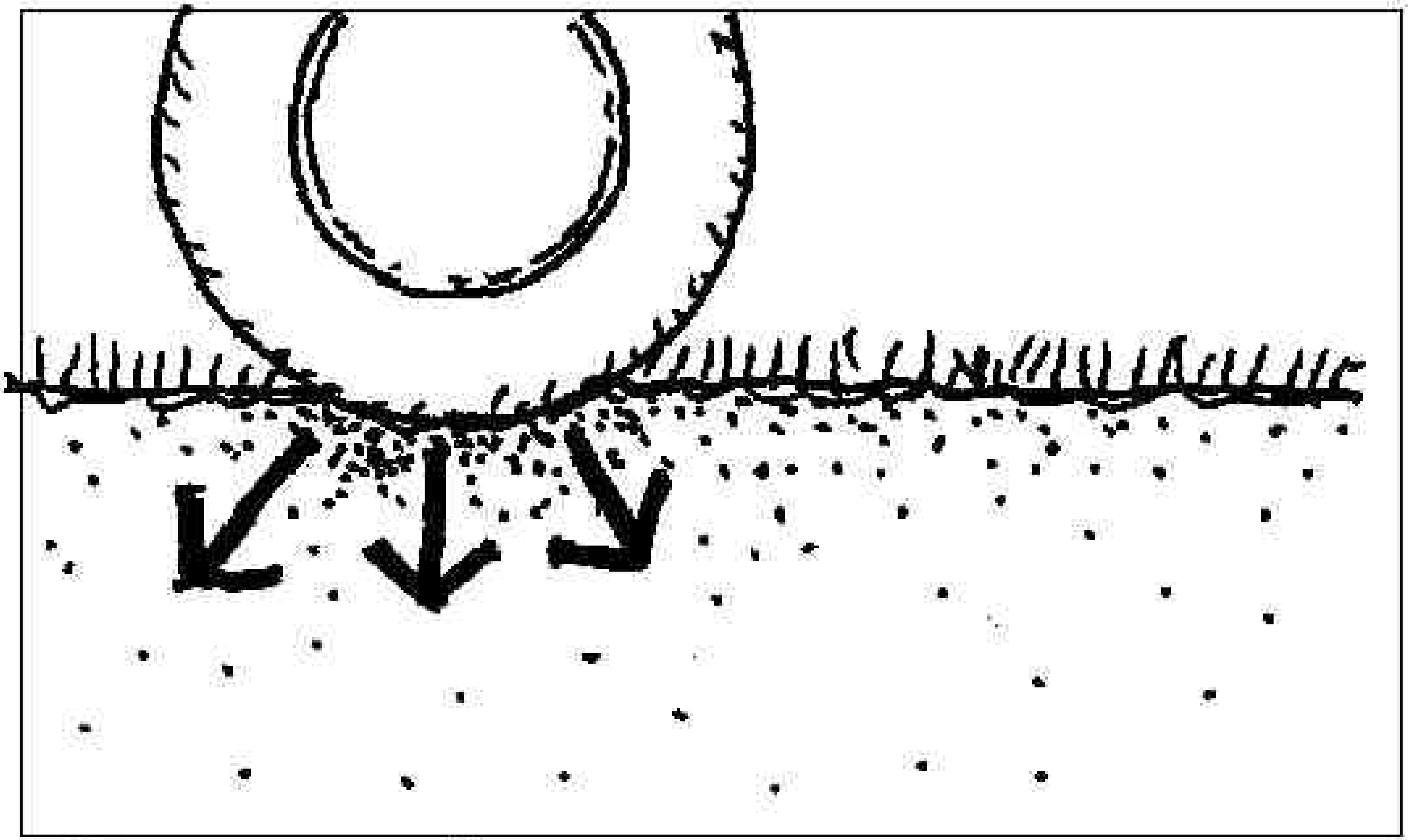
Don’t grind up your soil! Mix loosely to preserve the peds.



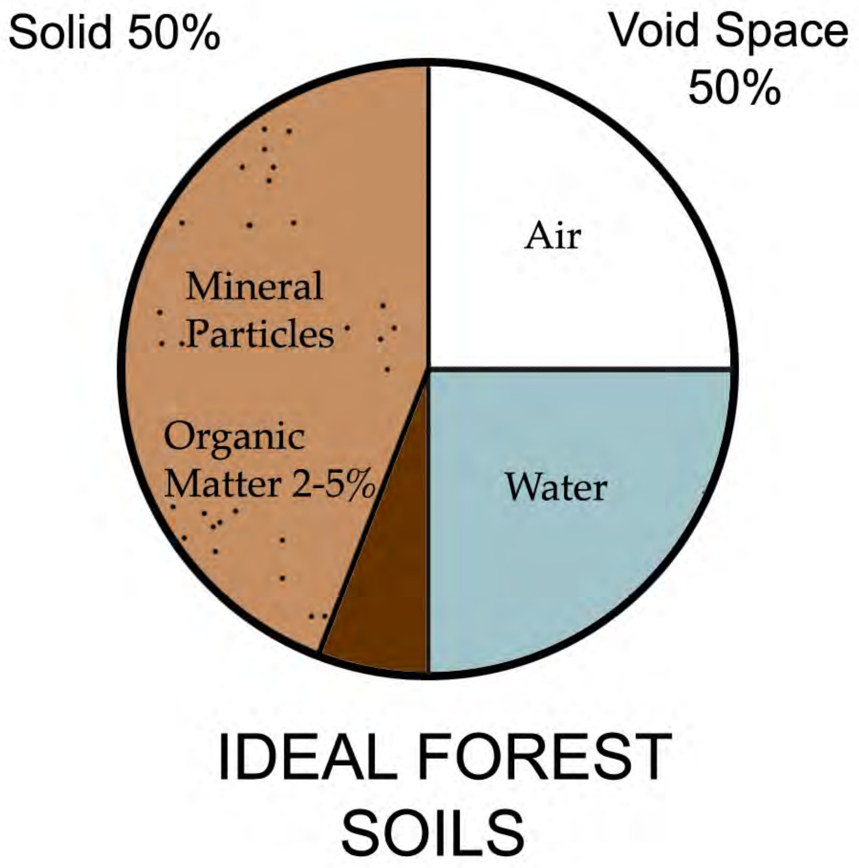
Organic amendments (compost) improve structure in all soil types, through biological activity and bio-chemical modifications.

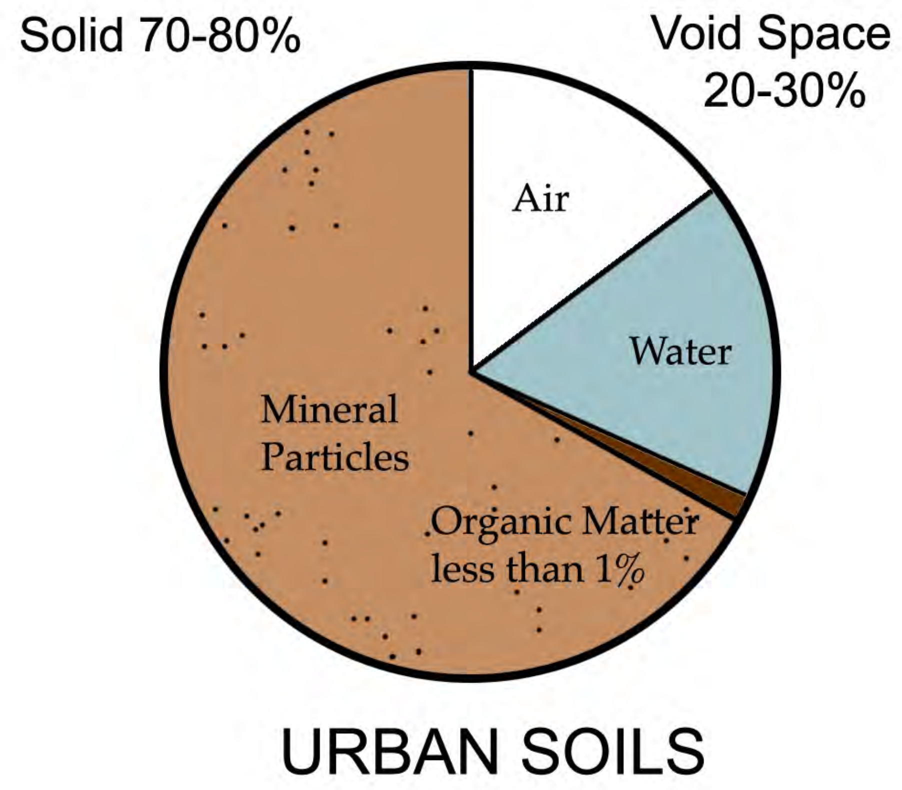
Sandy Loam Topsoil

Sandy Clay Loam Topsoil

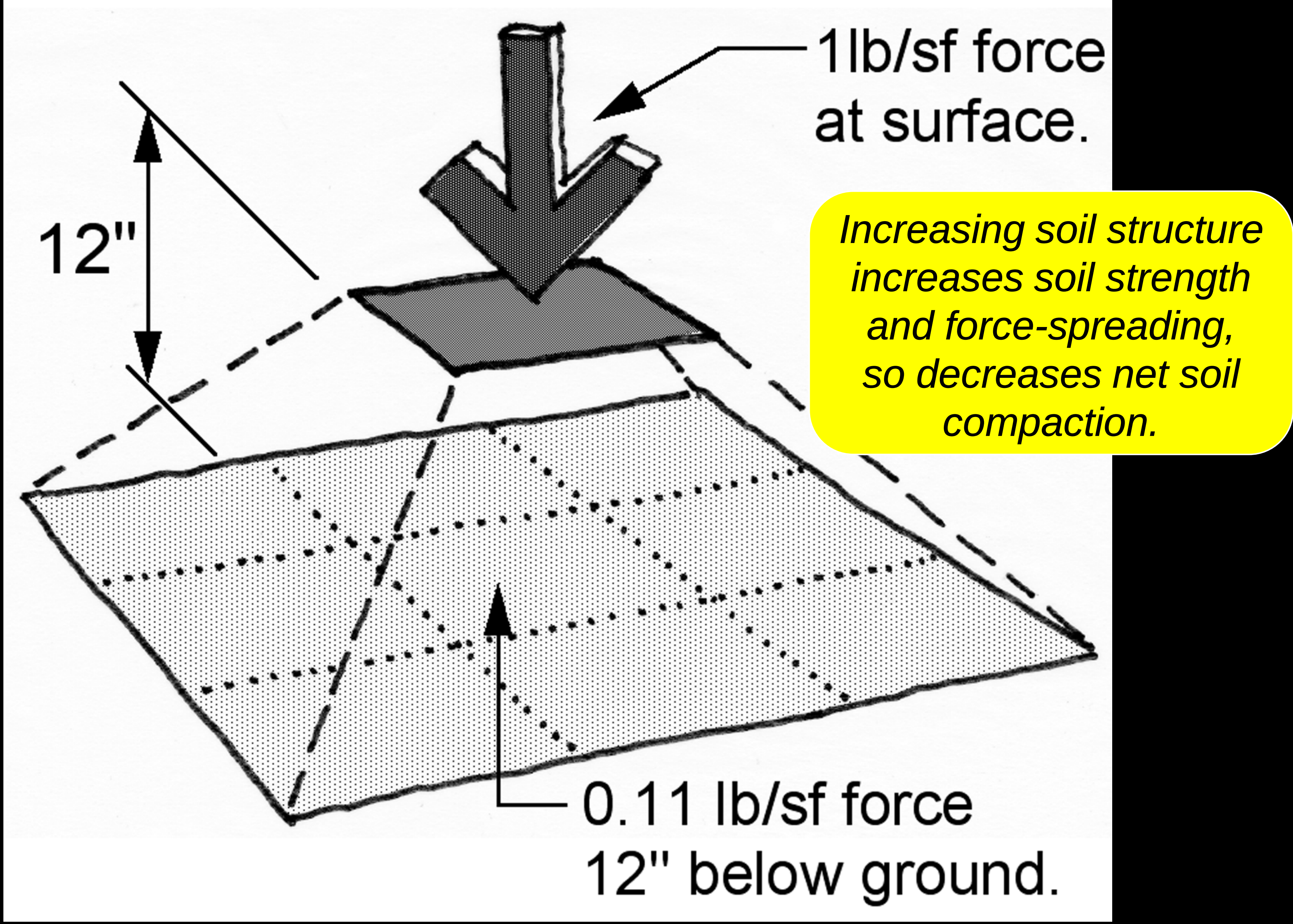


Density or Compaction





As compaction increases, pore space for water and air decreases



There is a decrease in compaction with depth as the compaction force spreads out into the soil in a cone shaped wave.

Units
% maximum bulk density standard proctor or Bulk density Lb/CF Dry weight

Densitometer
Moderately slow 10 minutes
Accurate
Expensive
Must calibrate to soil.
Readings impacted by OM
Soil service only

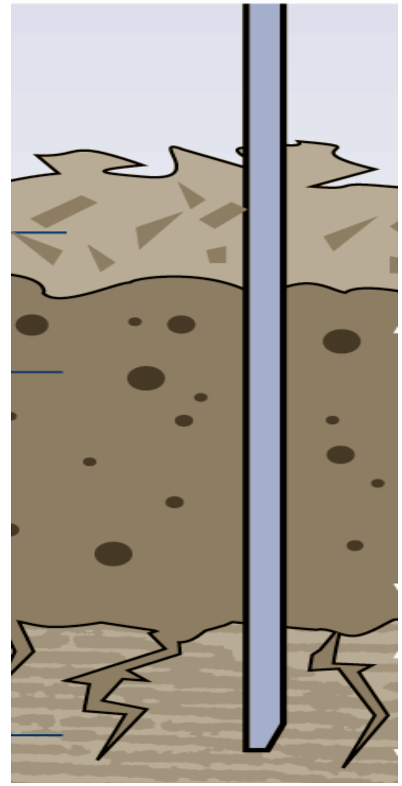
Units
PSI LB pressure per Sq Inch

Penetrometer
Fast less than one minute
Not very accurate
Soil moisture limited
Inexpensive
Anyone can operate

Units
Bulk density Lb/CF Dry weight

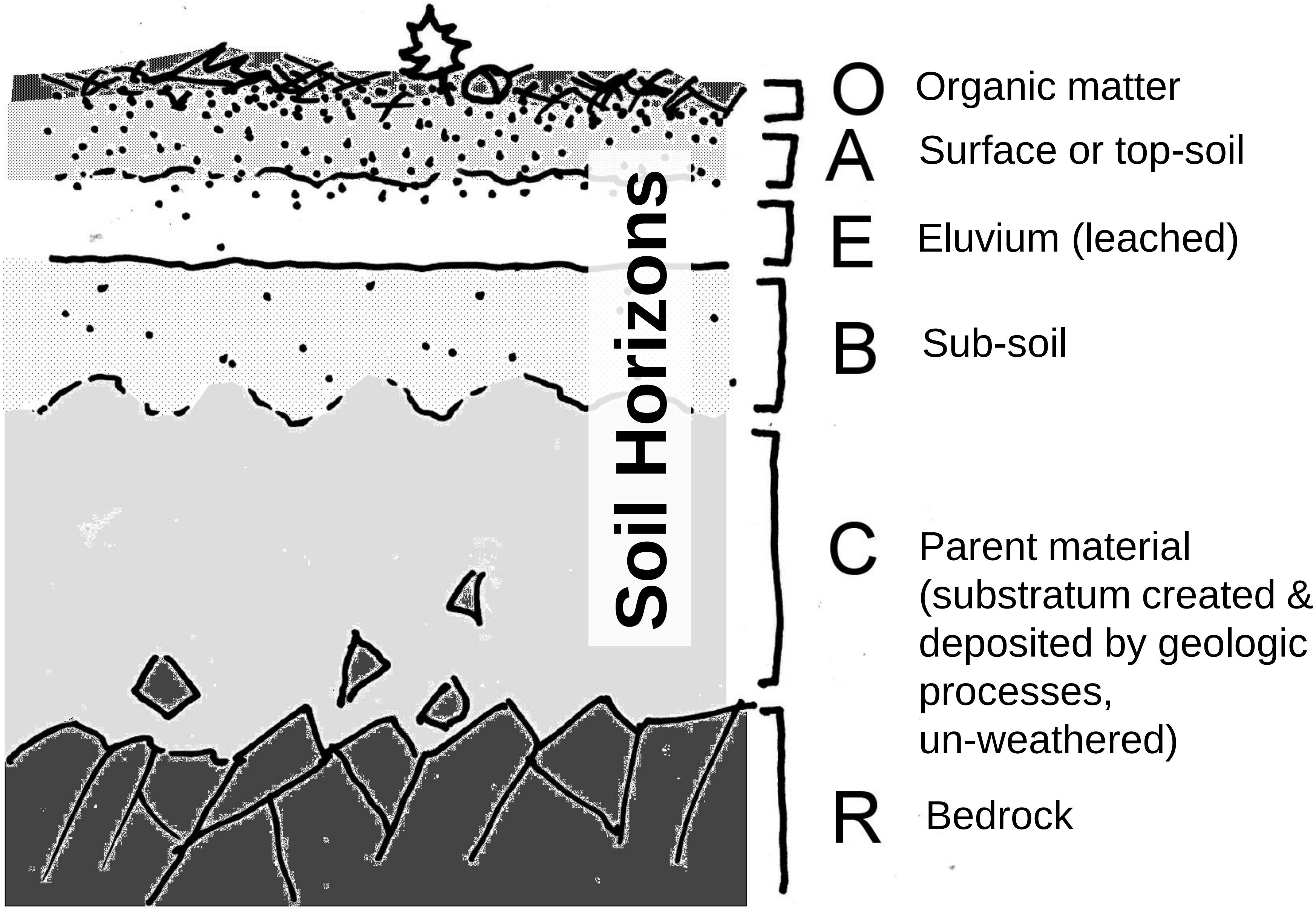
Bulk density cores
Slow one day
Accurate
Somewhat expensive
LA or soil service

<u>No Units</u>
Comparative feel only

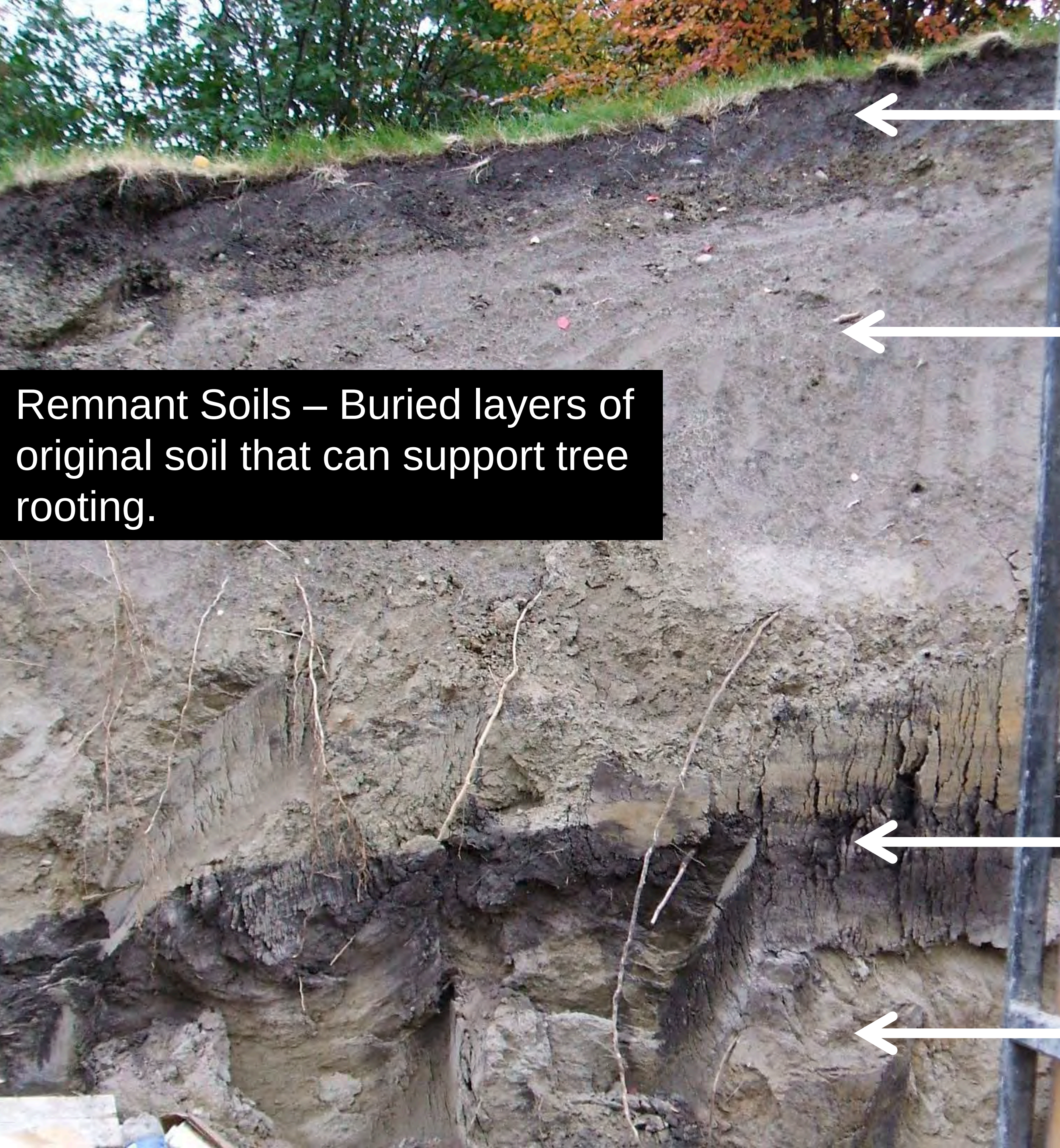


Rod penetrometer
Inexpensive 3/8" bar with T-handle, driven by inspector's weight: Inaccurate, but gives comparative feel for compacted or uncompacted conditions

Soil Compaction Testing



Soil Profile


Imported topsoil
Fill soil
Remnant Soils – Buried layers of original soil that can support tree rooting.
Remnant topsoil
Remnant subsoil

Examining a soil profile with a Dutch soil auger

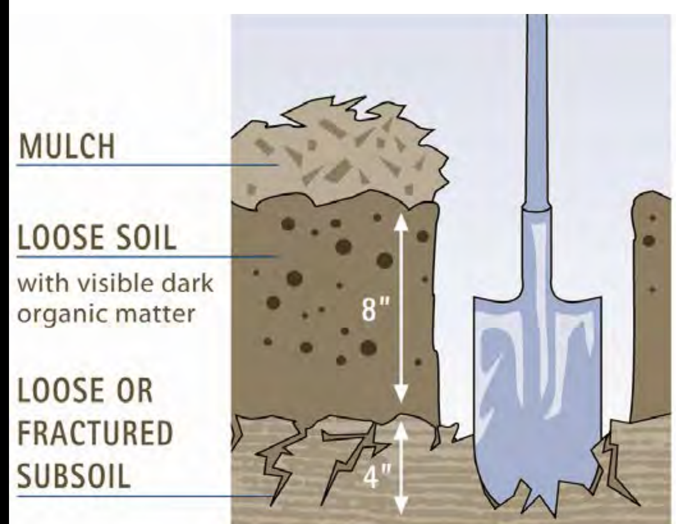
Examining a soil profile with a soil probe / core sampler

Only works 6 -12" deep, so better for lawns than trees.

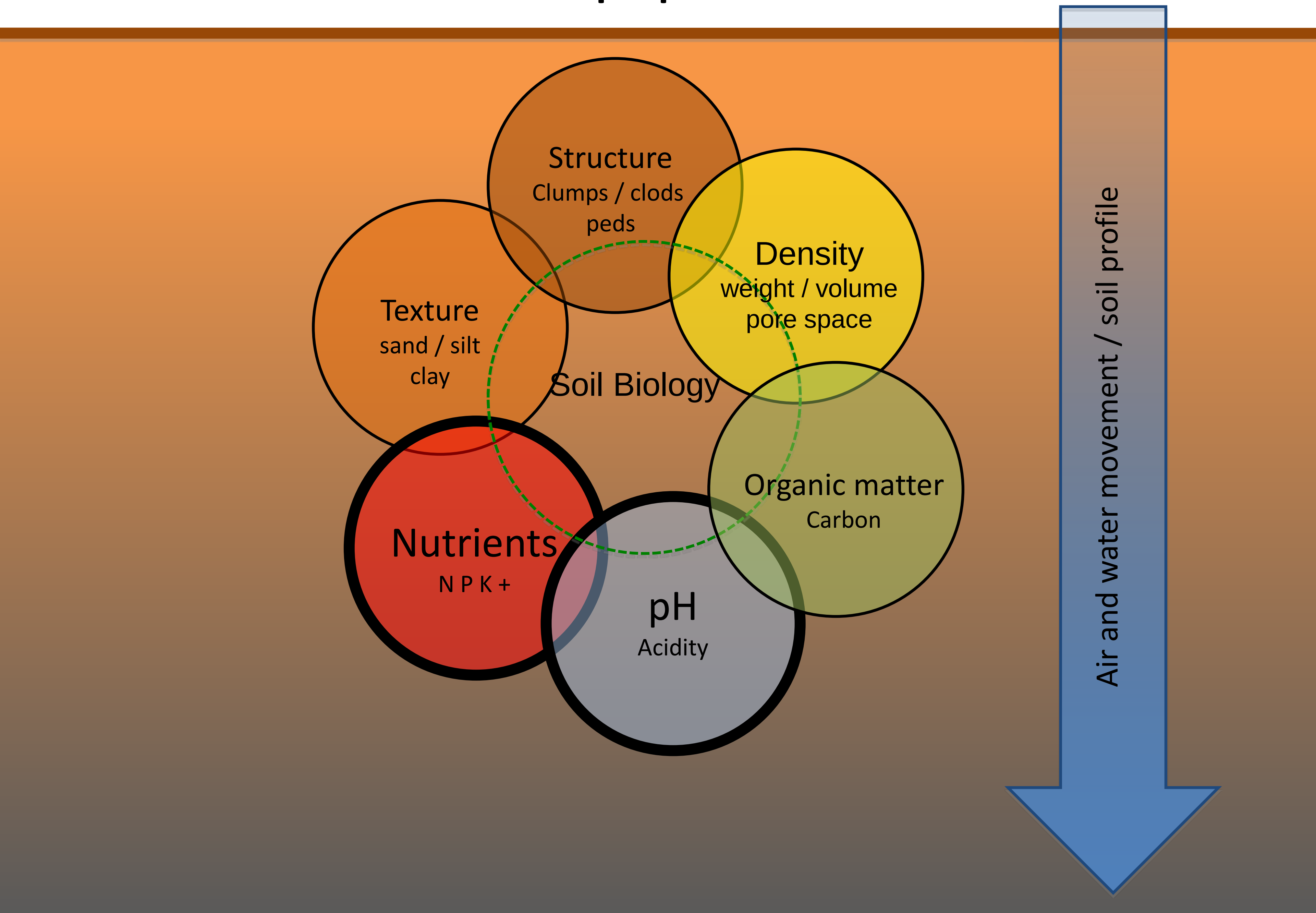
Compacted vs. Amended

Examining soil profile with shovel

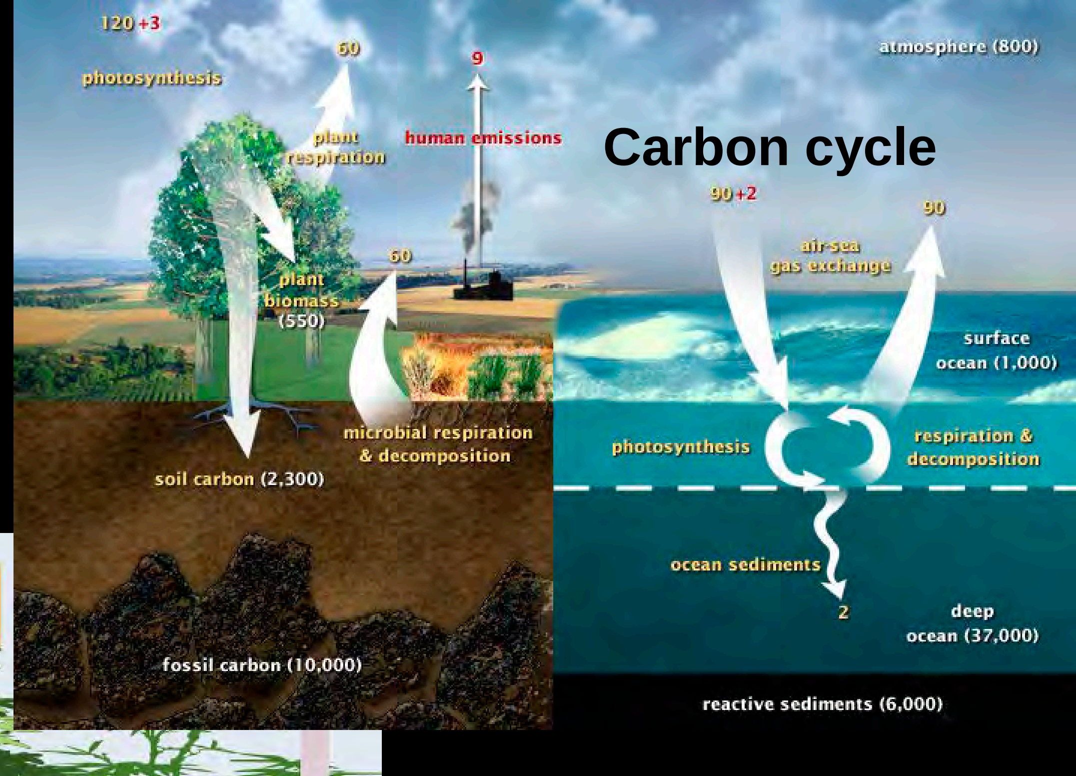
To verify scarification of subsoil and amendment of upper 8" with compost.

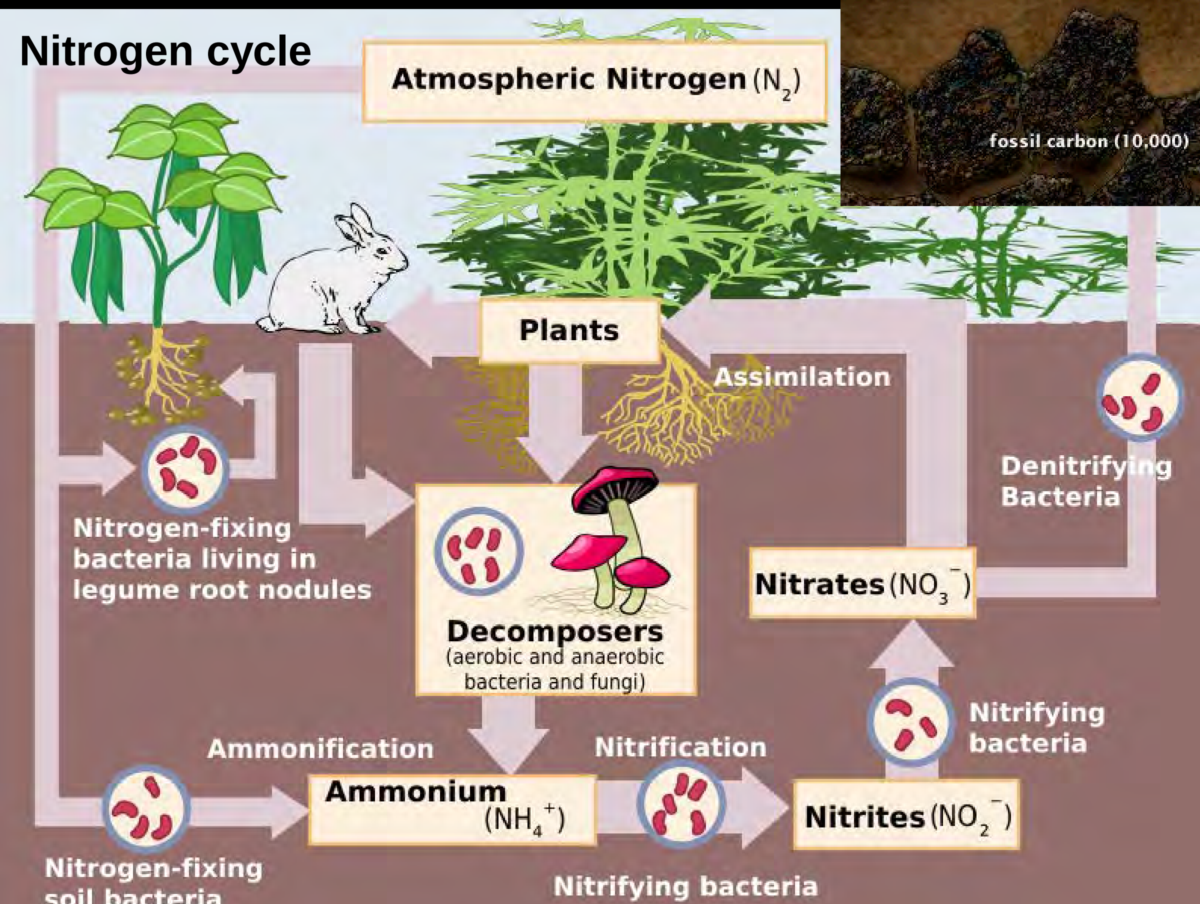


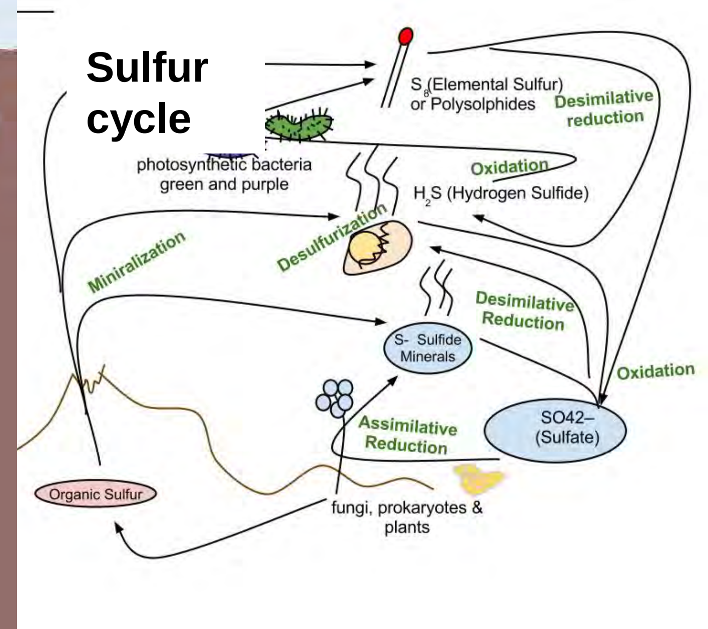
Chemical properties of soil



Chemical properties of soil
- *endless cycles*







Elements Required by Plants

Base elements	Macronutrients	Micronutrients
Oxygen (O)	Nitrogen (N)	Boron (B)
Hydrogen (H)	Phosphorus (P)	Chlorine (Cl)
Carbon (C)	Potassium (K)	Cobalt (Co)
	Calcium (Ca)	Copper (Cu)
	Magnesium (Mg)	Iron (Fe)
	Sulfur (S)	Manganese (Mn)
		Molybdenum (Mo)
		Zinc (Zn)

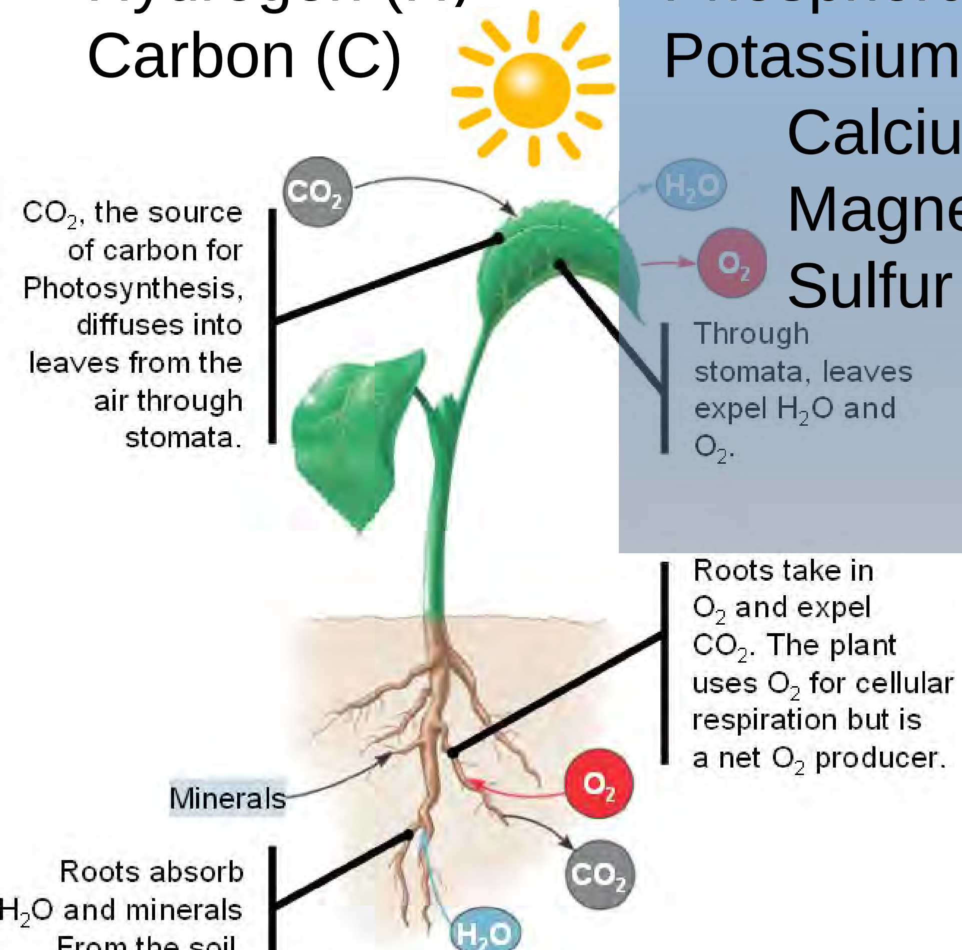
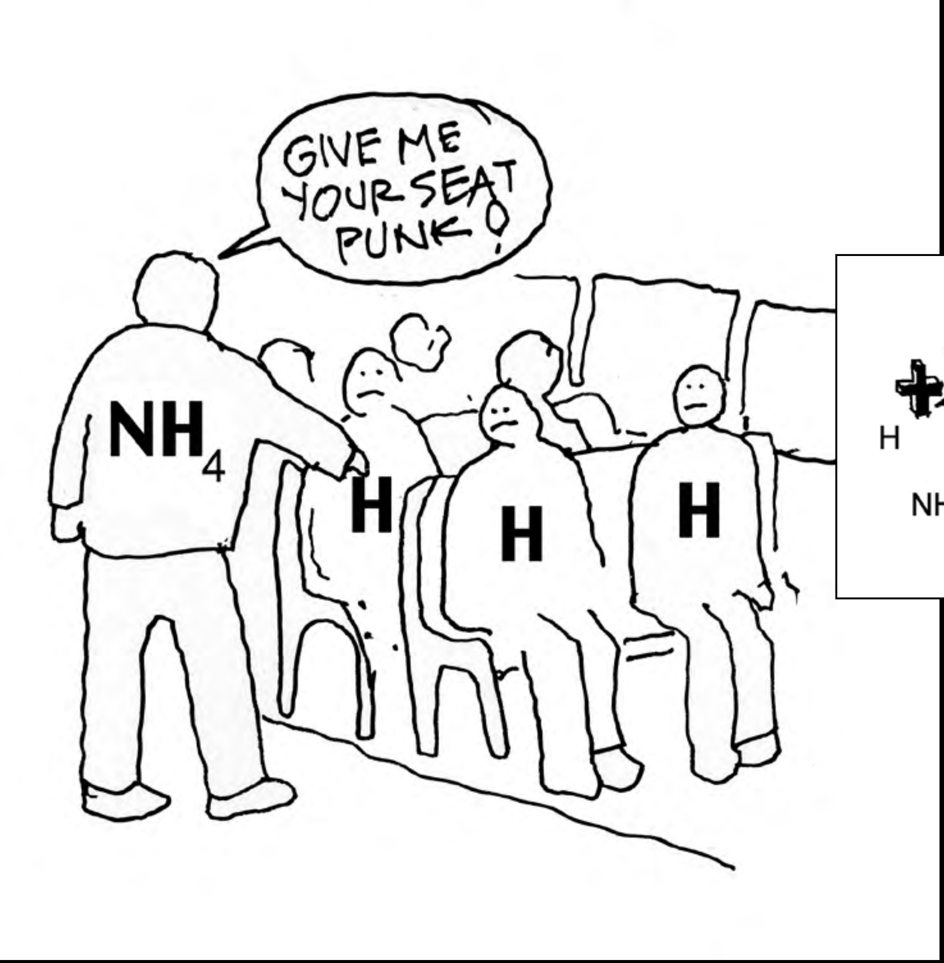
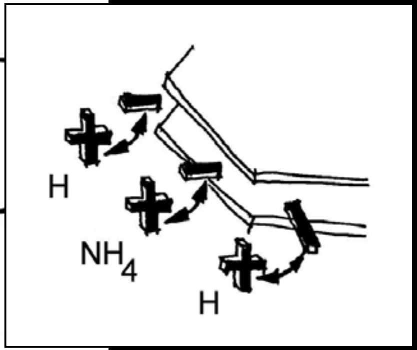
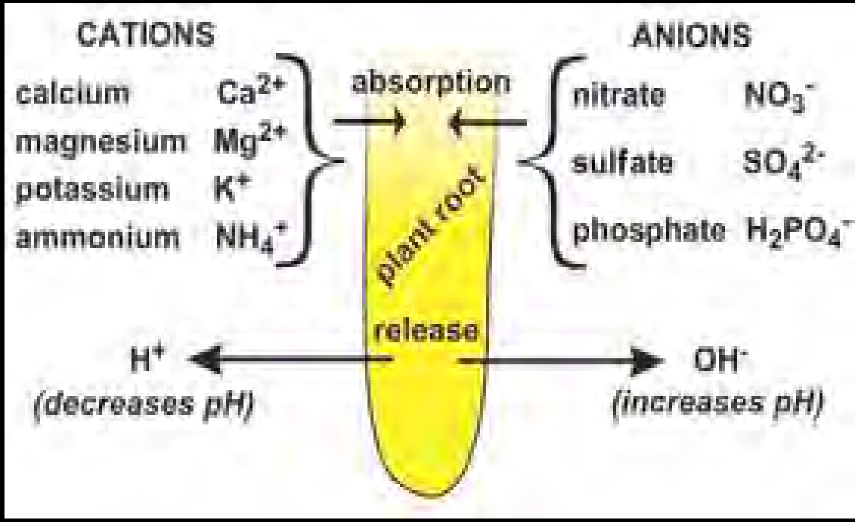


image: extension.missouri.edu

Cation Exchange Capacity (CEC)







The soil particle is like a bus. The seats are the negative charges. All the seats must always be full with positively charged particles. Hydrogen has a weak charge and Ammonium (NH_4) a stronger charge, so they “exchange” seats if the Ammonium Nitrogen ion wants to sit down.

Lowering pH (increasing acidity) increases availability of cations, but decreases availability of anions.

Sand

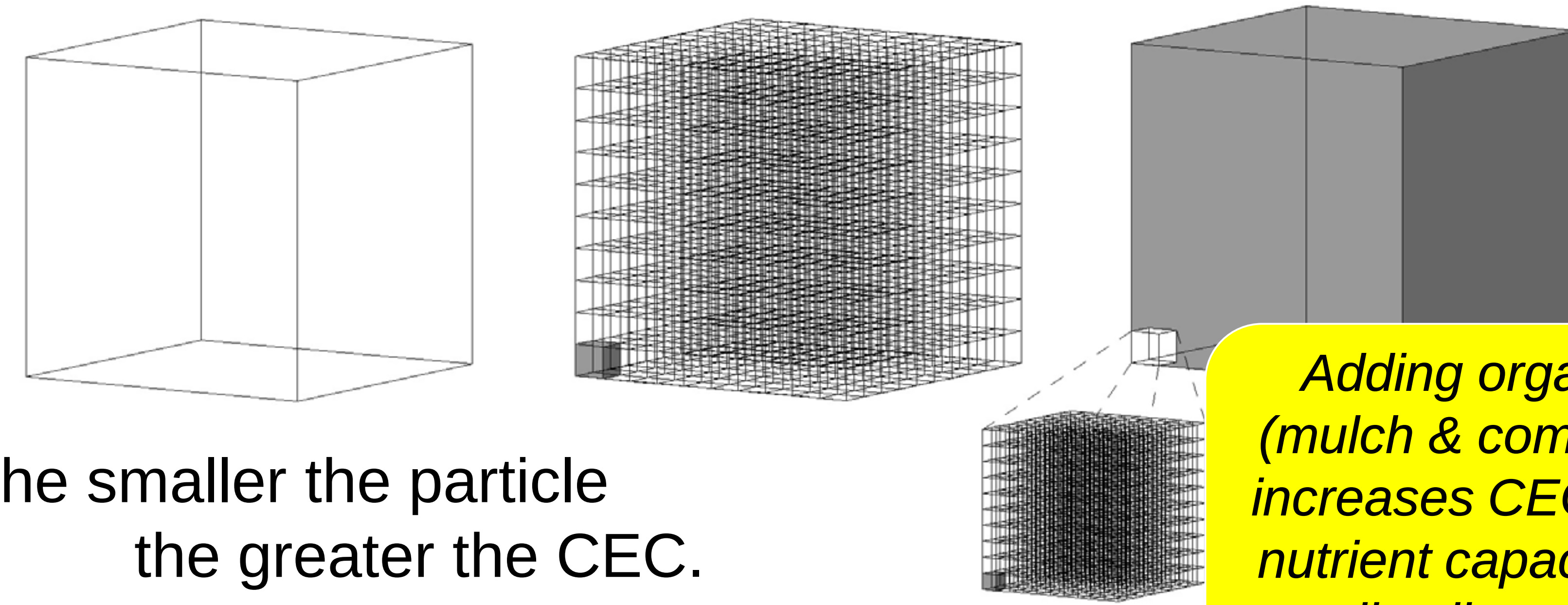
1 Particle Fine **Sand** .2mm
0.24mm^2 Surface Area

Silt

1,000 Particles **Silt** .02mm
2.4 mm^2 Surface Area

Clay

1,000,000 Particles **Clay** .002 mm
24 mm^2 Surface Area



Adding organic (mulch & compost) increases CEC and nutrient capacity of all soil types.

The smaller the particle
the greater the CEC.
Humus/clay colloids have the most!

Cation Exchange Capacity *(CEC) for planting soil mixes*

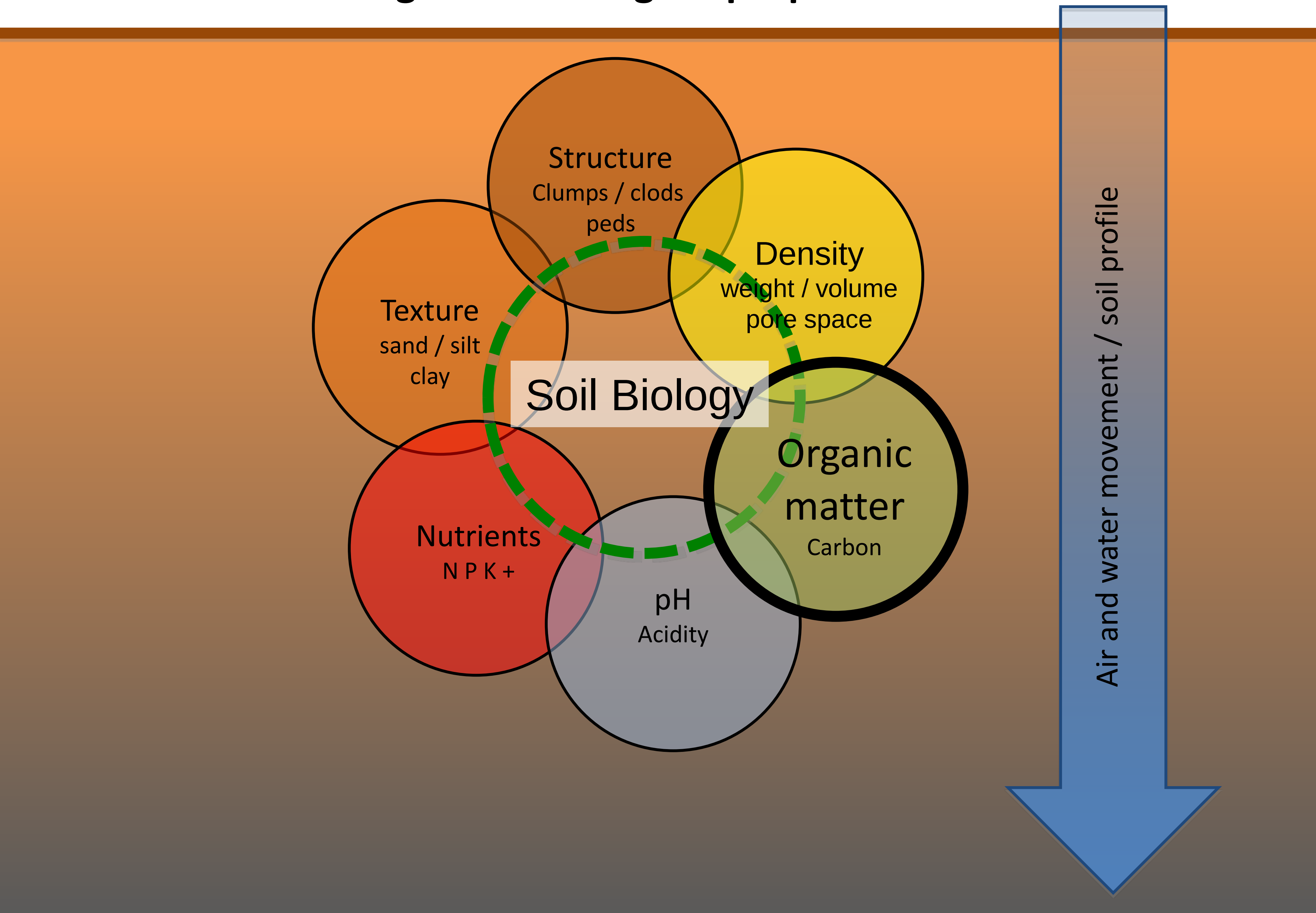
Low fertility soil	Less than 5
Medium fertility	5-10
High fertility	10-30
Compost/humus	**up to 200!**

USDA pH Classification

	pH range	
Ultra acid	1.8 - 3.4	Toxic to most plants
Extremely acid	3.5 - 4.4	Restrictive to most plants
Very strong acid	4.5 - 5.0	
Strongly acid	5.1 - 5.5	Acid-tolerant plants
Moderately acid	5.6 - 6.0	
Slightly acid	6.1 - 6.5	Best nutrient availability for most plants
Neutral	6.6 - 7.3	
Slightly alkaline	7.4 - 7.8	Alkaline-tolerant plants
Moderately alkaline	7.9 - 8.4	
Strongly alkaline	8.5 - 9.0	Restrictive to most plants
Very strongly alkaline	9.1 - 11.0	Toxic to most plants

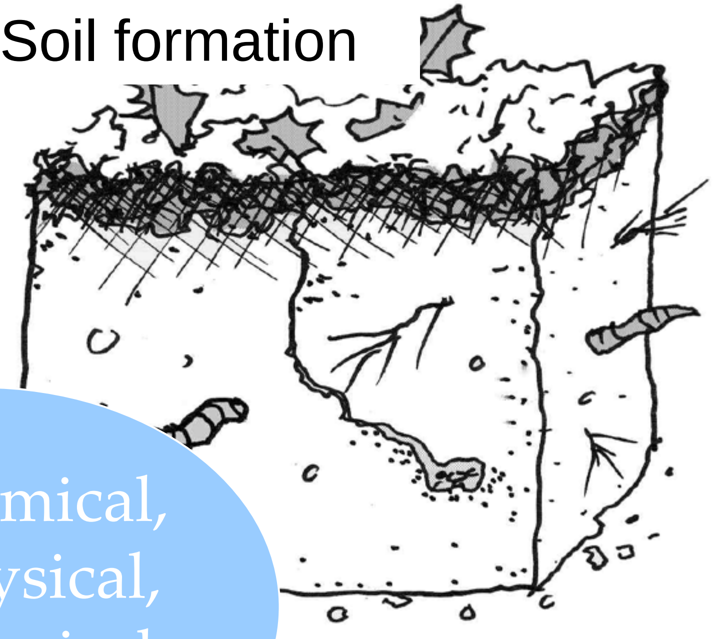
Lower or higher pH decreases availability of different nutrients
Humus (compost) buffers ph towards optimal 6.3 to 6.8

Organic & Biological properties of soil



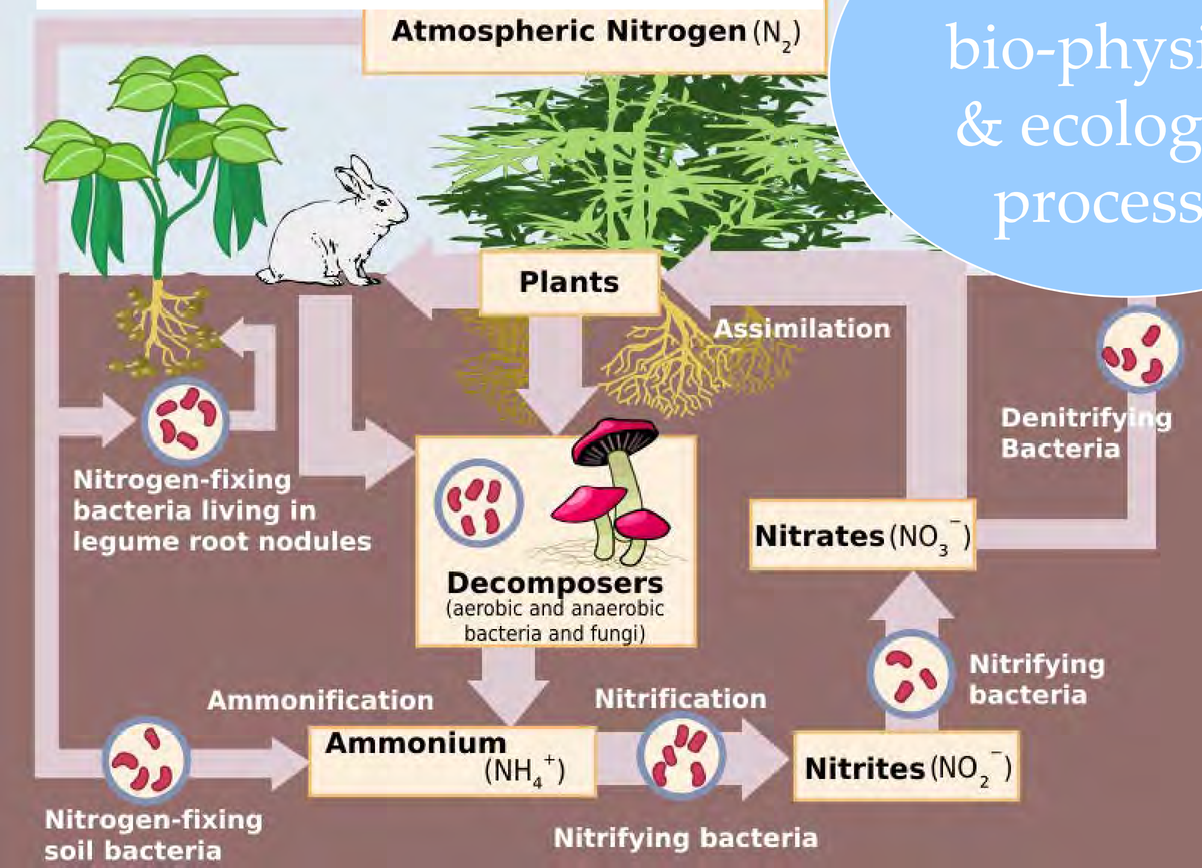
Organic Properties of Soil – *biology in action!*

Soil formation

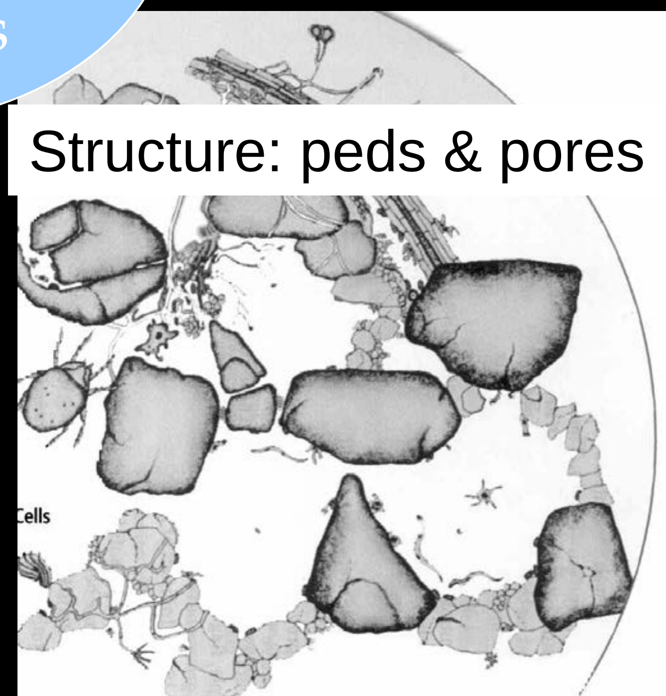


bio-chemical, bio-physical, & ecological processes

Nutrient cycling & availability



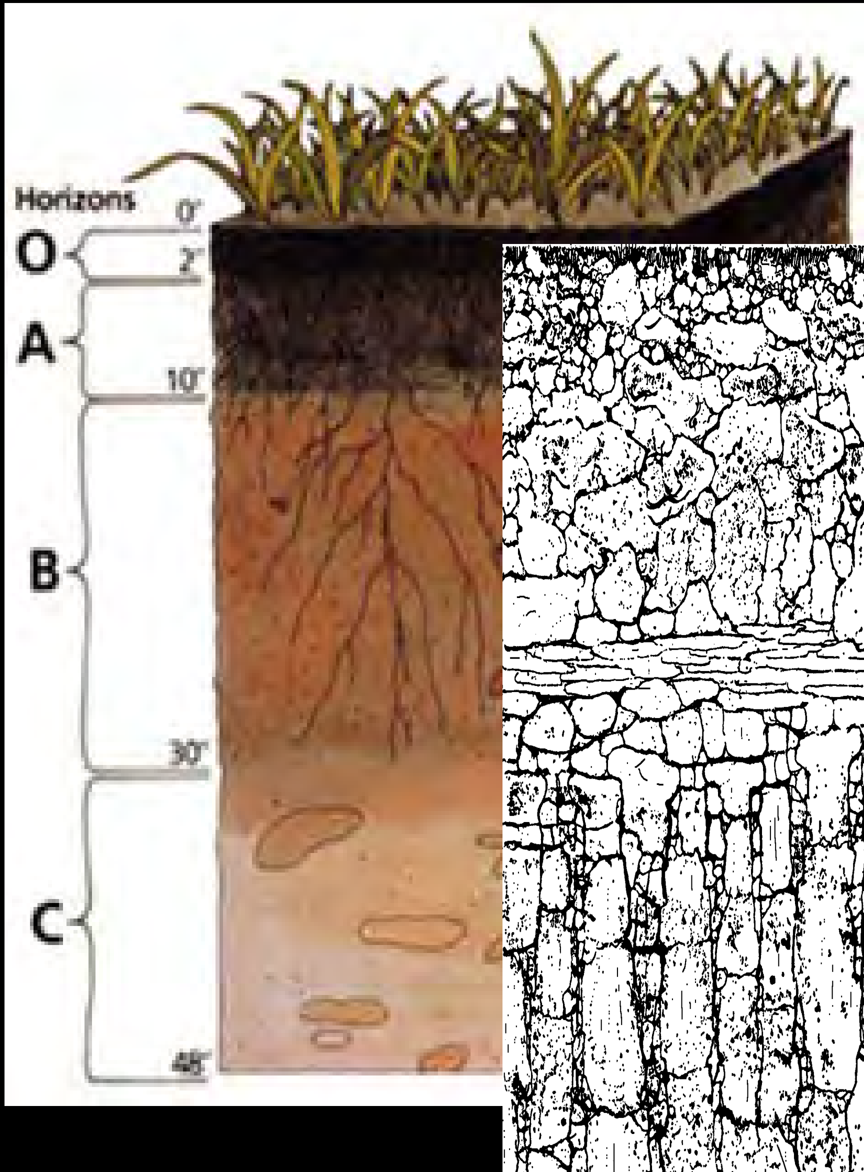
Structure: peds & pores



Soil development processes, from parent "dirt" & rock

<u>Soil horizons & their evolution</u>

- Substratum (C) or bedrock (R) weathers physically & chemically to subsoil (B)
- Primarily <u>biological</u> processes create topsoil (A) and organic (O) horizons

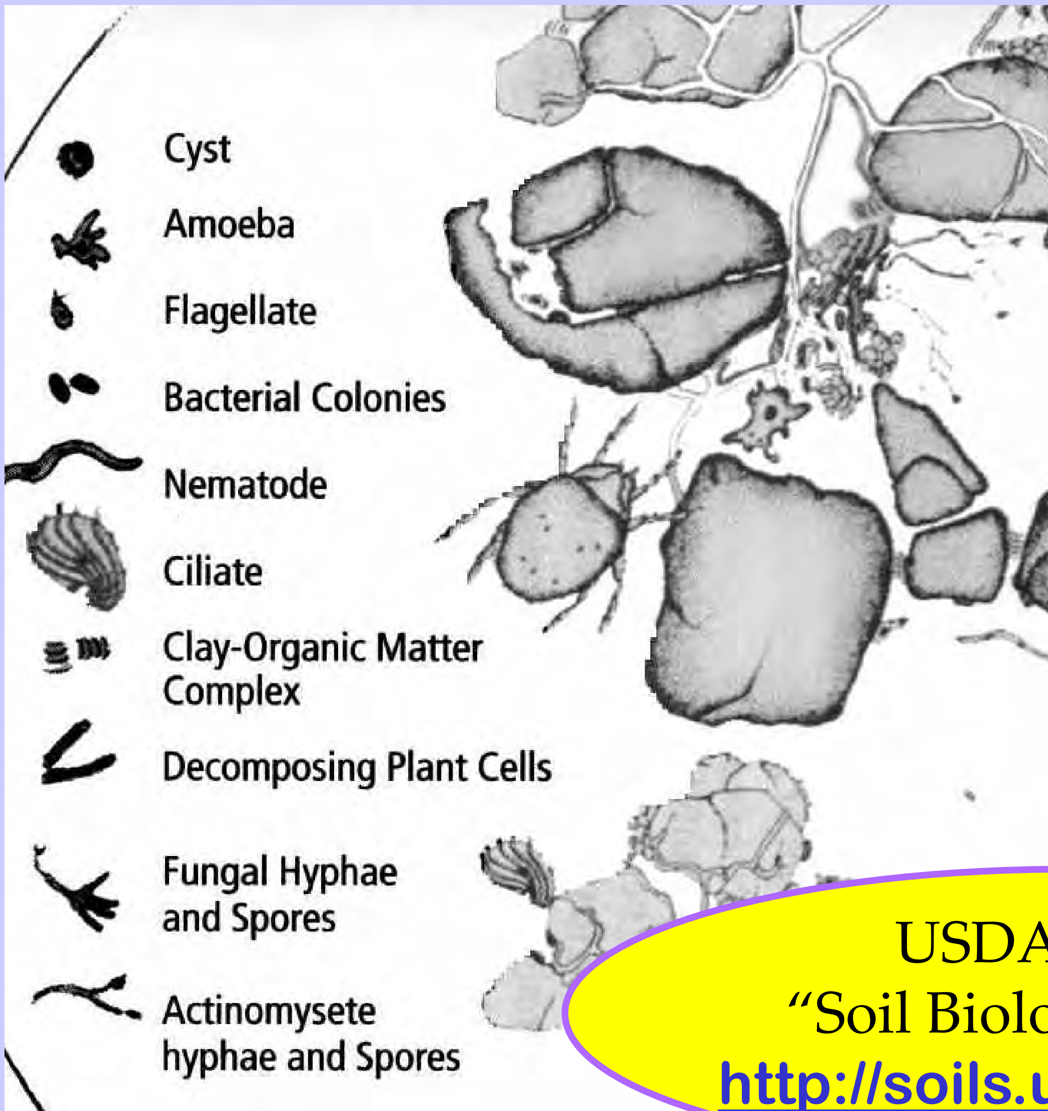


USDA - NRCS

http://soils.usda.gov

Understanding Soil Biology
Soil life provides essential functions

Soil
is
alive!

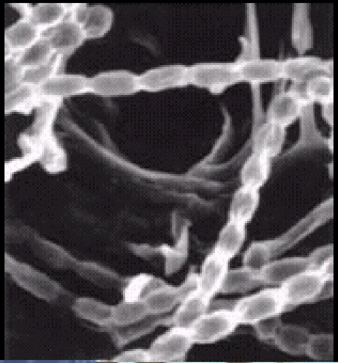


USDA-NRCS
"Soil Biology Primer"
http://soils.usda.gov/sqi/

S. Rose & E.T. Elliott

Common organisms in the soil foodweb

Bacteria



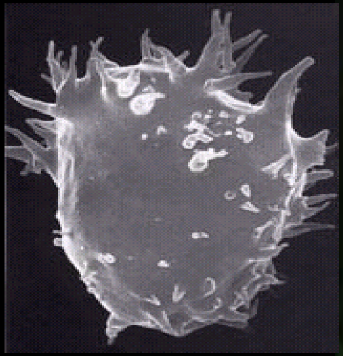
Fungi

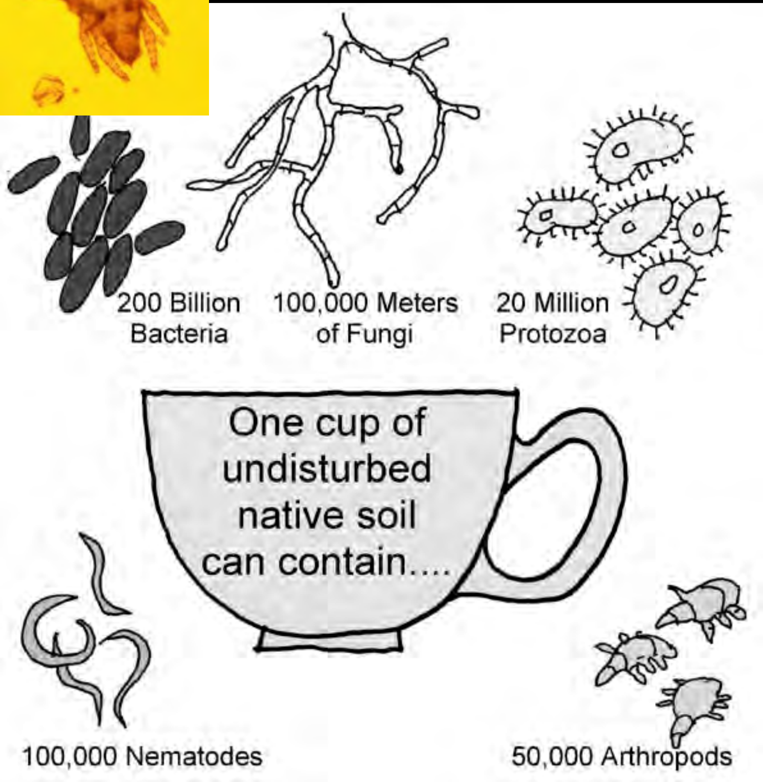
Nematodes

Arthropods

Earthworms

Protozoa



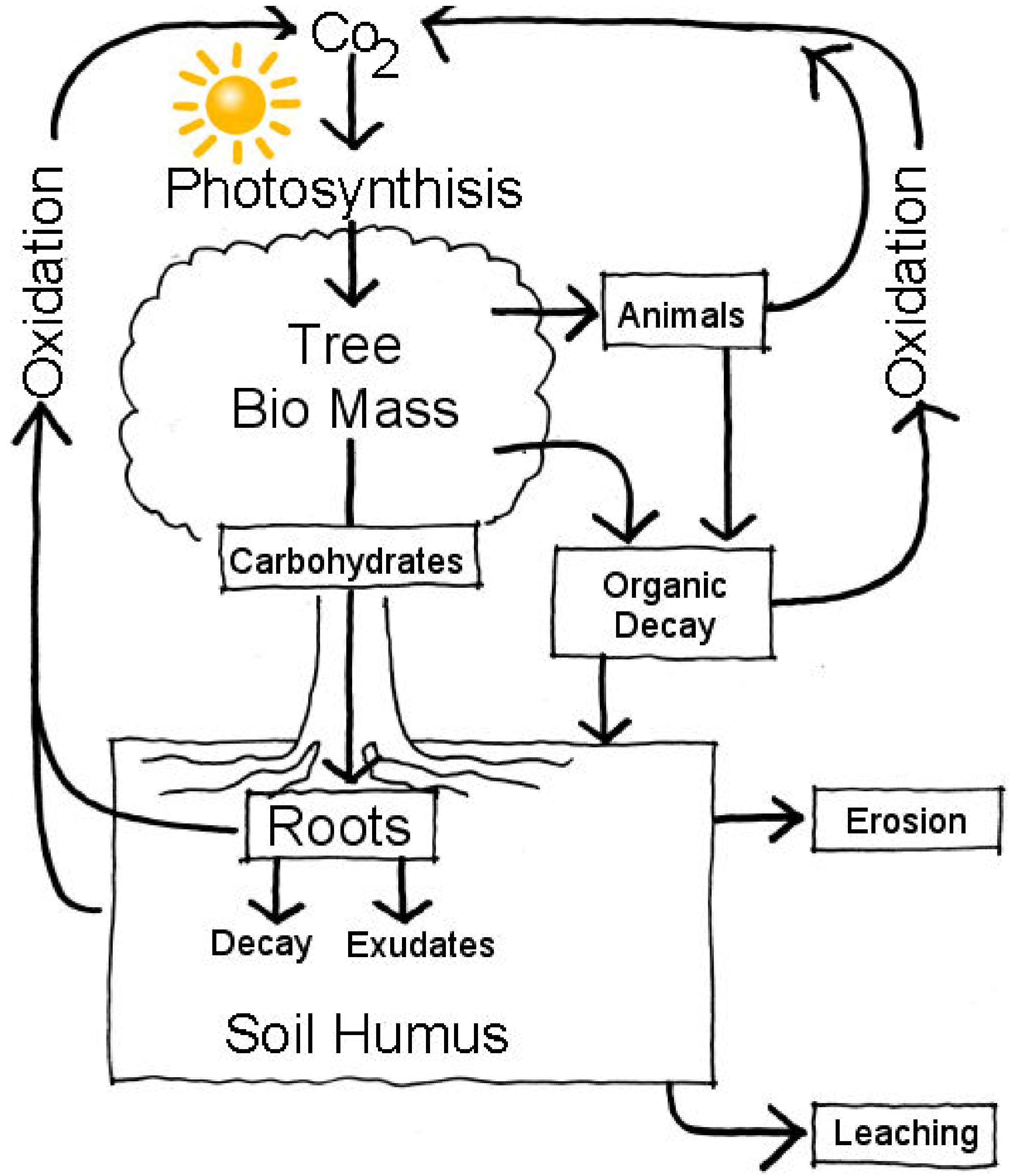


What Fuels the Soil Foodweb?

Plant photosynthesis:

Sunlight → living and dead organic matter

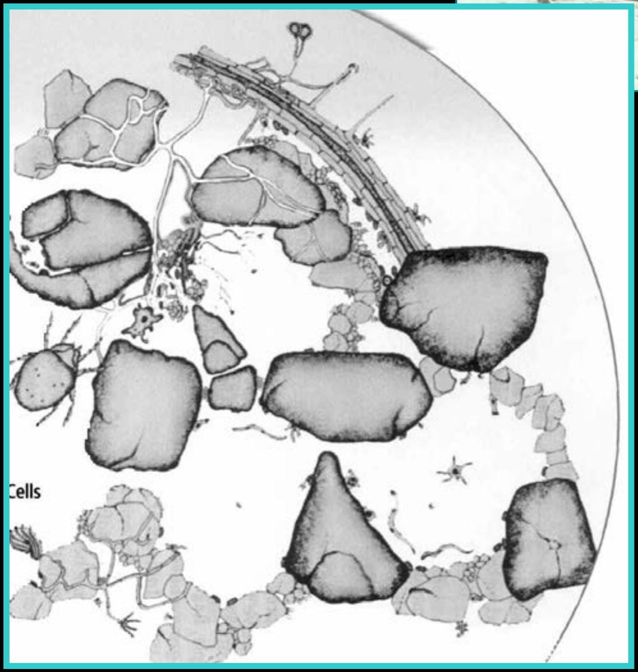
Plants exude 20-30% of their photosynthetic energy as carbohydrates released in the root zone to feed beneficial soil organisms (bacteria & fungi).



Restoring soil life, to restore soil functions

Soil organisms create:

- soil structure
- fertility = nutrient cycling
- plant disease protection
- Bio-filtration
- erosion control
- stormwater detention & moisture capacity



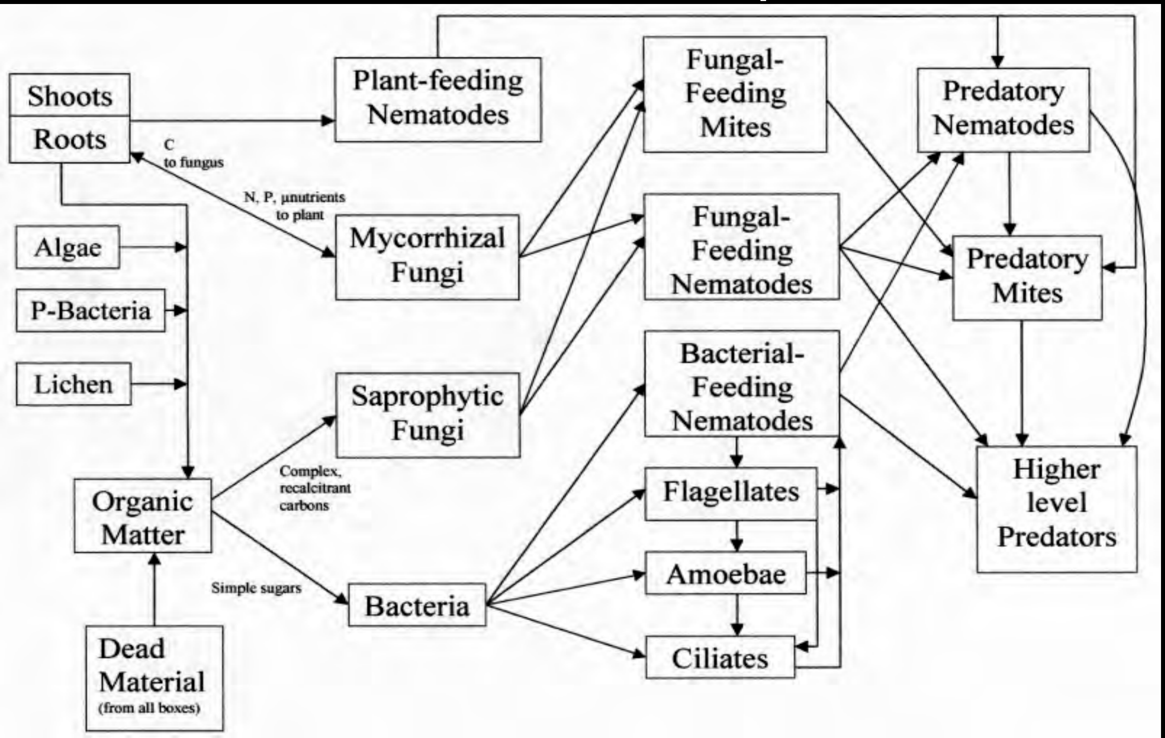
Compost kickstarts the soil ecosystem!
(Provides food and home for organisms)

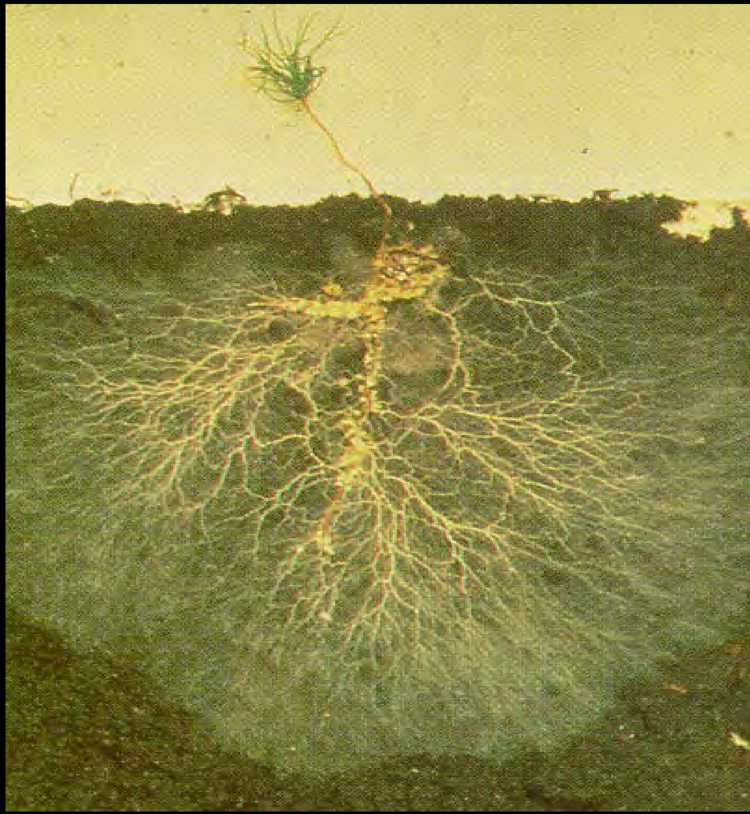
How does soil life create soil structure?

- Bacteria secretions glue clays, silts and sands together into micro-aggregates.
- Micro-aggregates are bound together by fungal hyphae, root hairs and roots.
- Spaces are made by moving arthropods & earthworms, and decaying roots.
- Only when all organisms are present can roots and water move into the soil with ease.

How does soil life provide fertility (nutrient cycling)?

- Soil foodweb stores nutrients in living & dead organic matter
- Nutrients are released in root zone as organisms eat and excrete “waste” (nitrogen, etc.)
- Mycorrhizal fungi bring nutrients and water to roots of plants



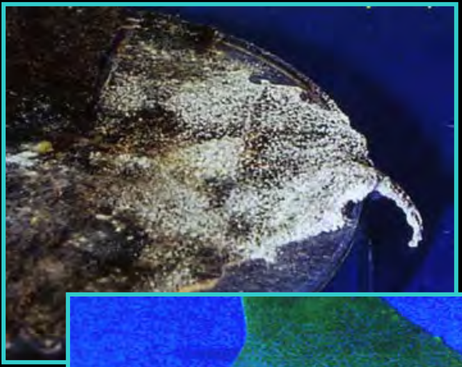


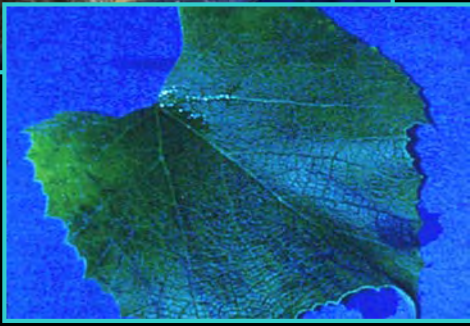
Dr. Michael P. Amaranthus, Mycorrhizal Applications Inc.

How does soil life provide plant disease protection?

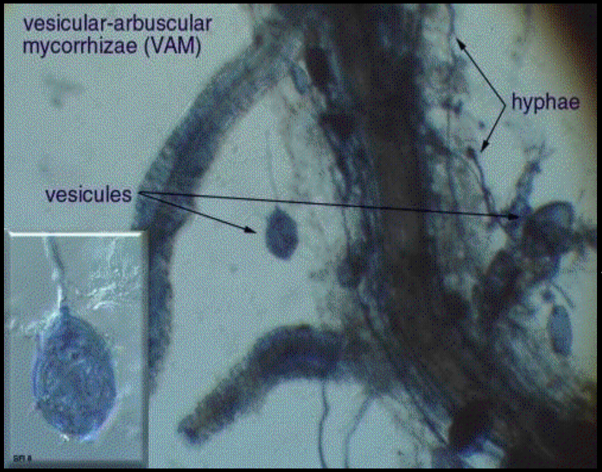
Diversity ⇒ predation, parasitization & competition with the few disease-causing organisms

- Bacteria cover leaf surfaces, block infection



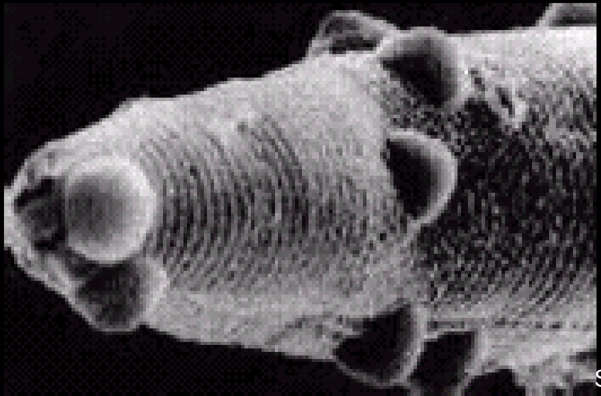


- Ecto- and endo-mycorrhizae prevent root infection

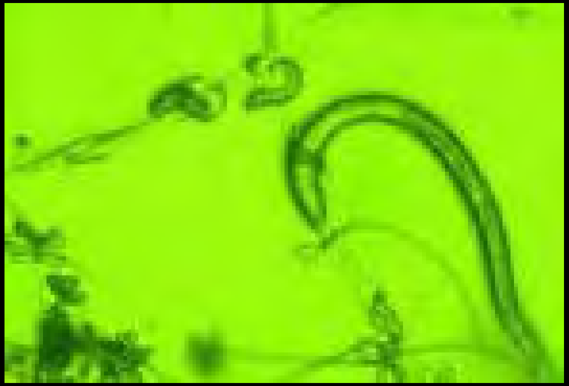


Soil Foodweb Inc.

- Many organisms prey on the few disease-causing organisms



SSSA

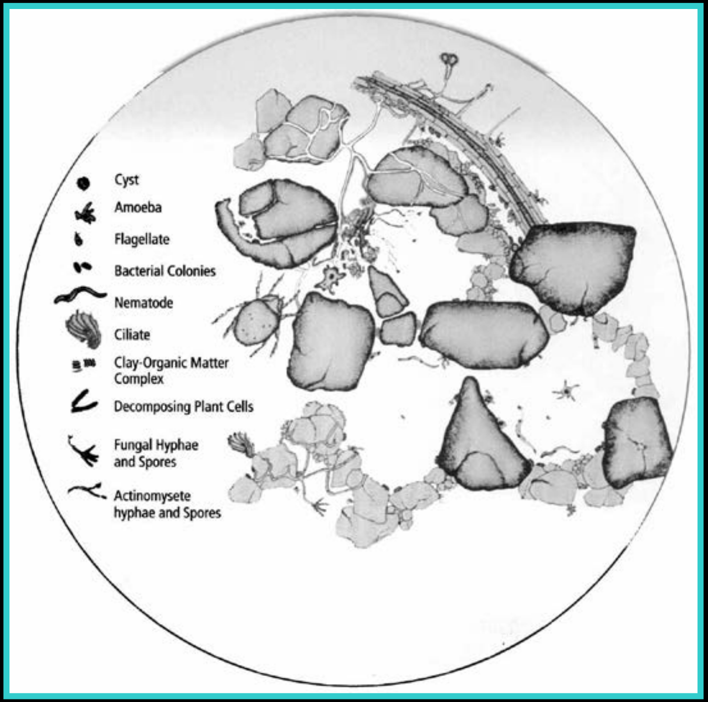


How does soil life filter out urban pollutants?

- Creates structure
- Breaks down hydrocarbons, pesticides
- Converts fertilizers to stable forms, so they are available to plants but won't wash away
- Binds heavy metals in soil, so they don't wash into streams

How does soil life provide stormwater detention / infiltration?

- Builds soil structure, moisture-holding capacity
- Increases surface porosity



UW trials, turf on glacial till soil

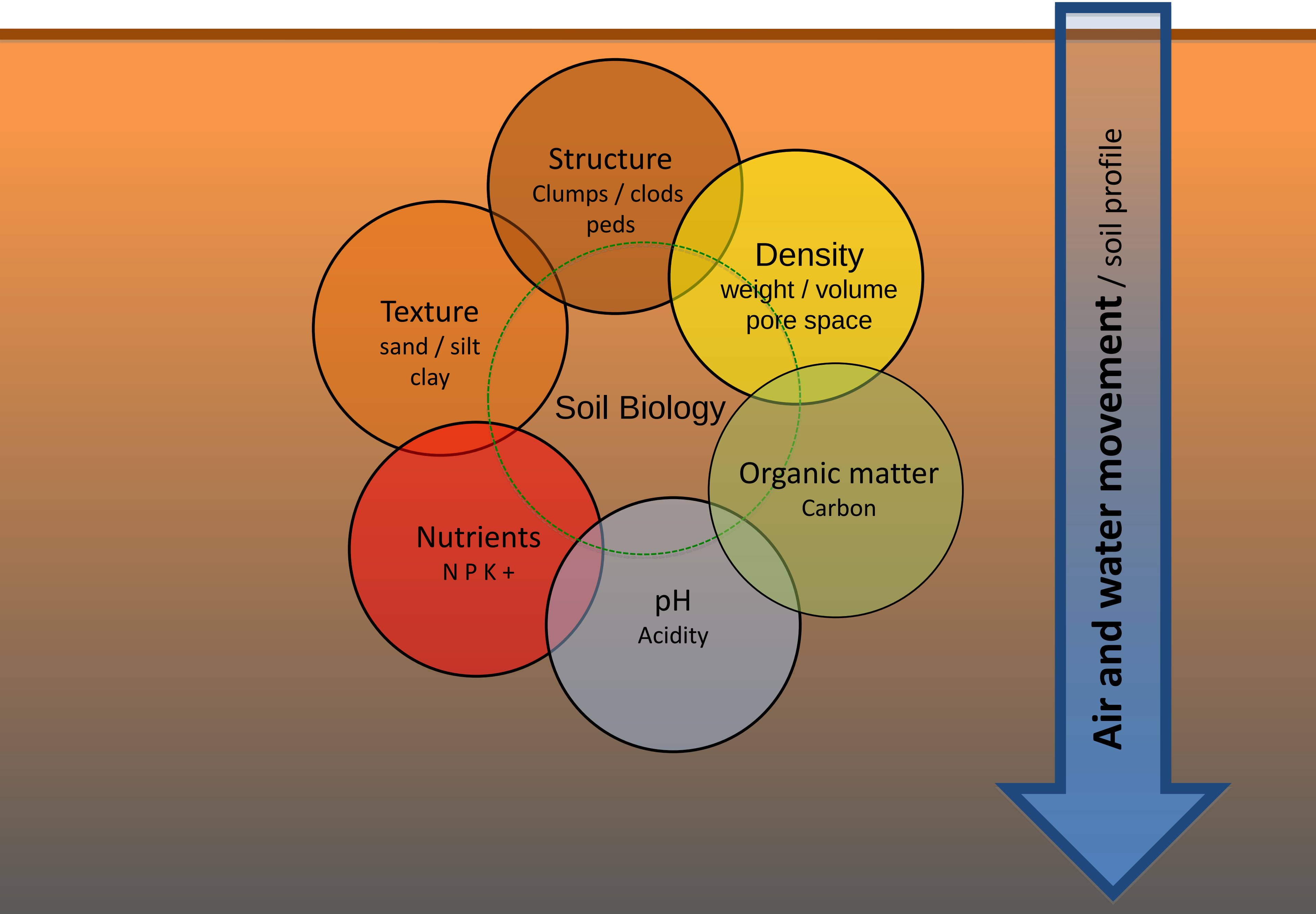
Compost-amended till soil – up to 50% reduction in storm water runoff

How can we enhance & restore soil biodiversity, to improve plant growth, water quality, and reduce runoff?

- Prevent /reduce compaction (keep heavy machinery off)
- Reduce intensive use of pesticides & soluble fertilizers
- Incorporate compost into soil, and mulch regularly, to <u>feed</u> <u>soil</u> <u>life</u>

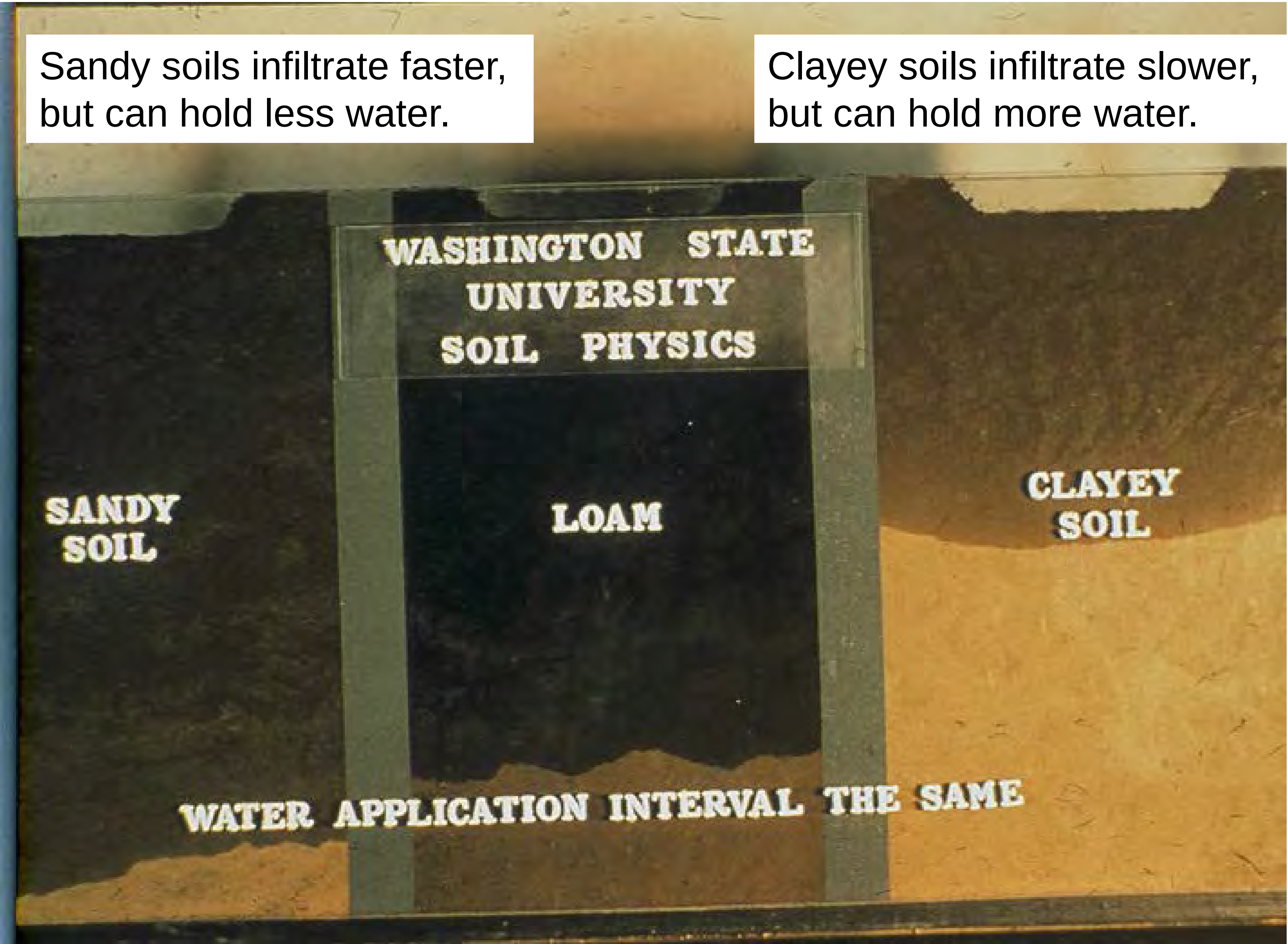
organic matter + soil organisms + time
creates ⇒
soil structure, biofiltration, fertility, & stormwater detention

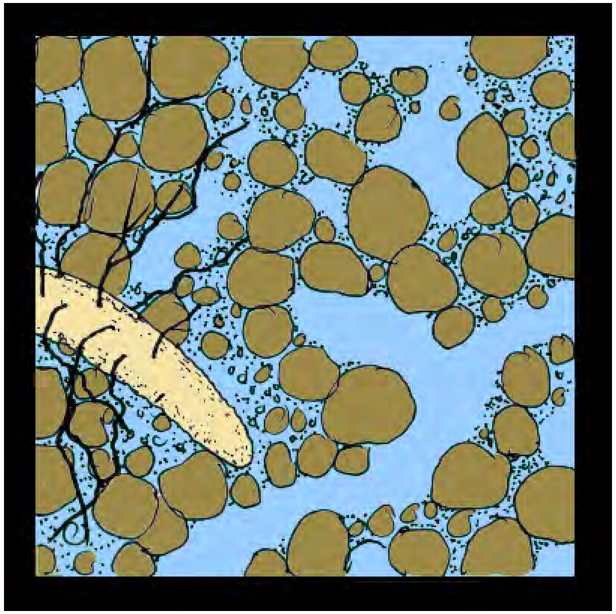
Air and water movement in soil



Sandy soils infiltrate faster, but can hold less water.

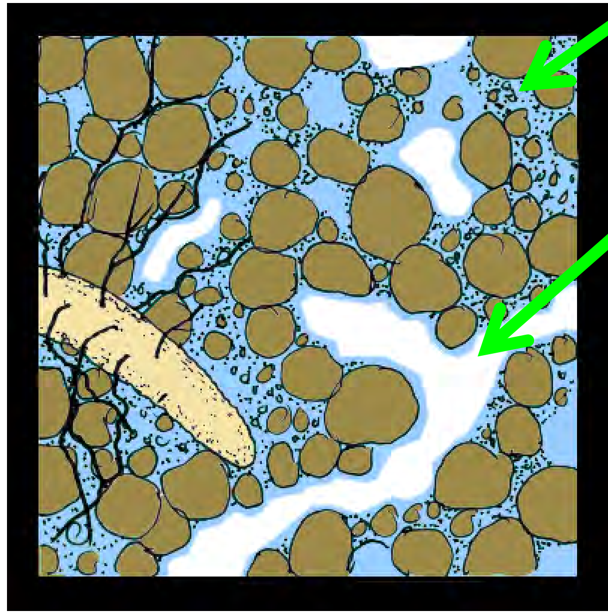
Clayey soils infiltrate slower, but can hold more water.





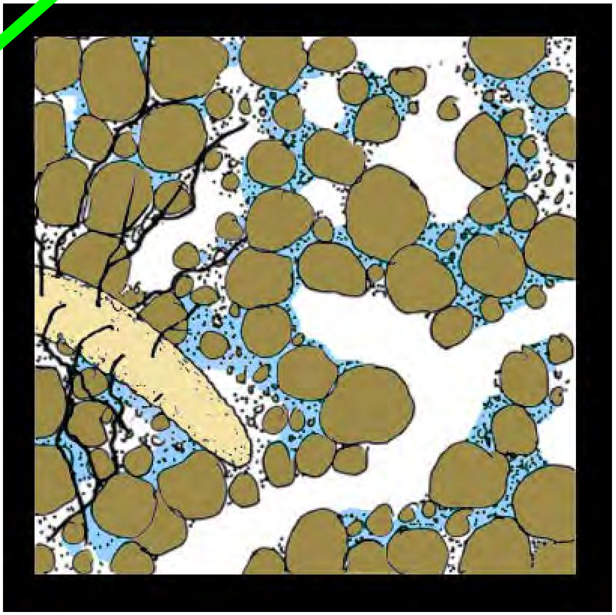
Saturation Point

all pores full



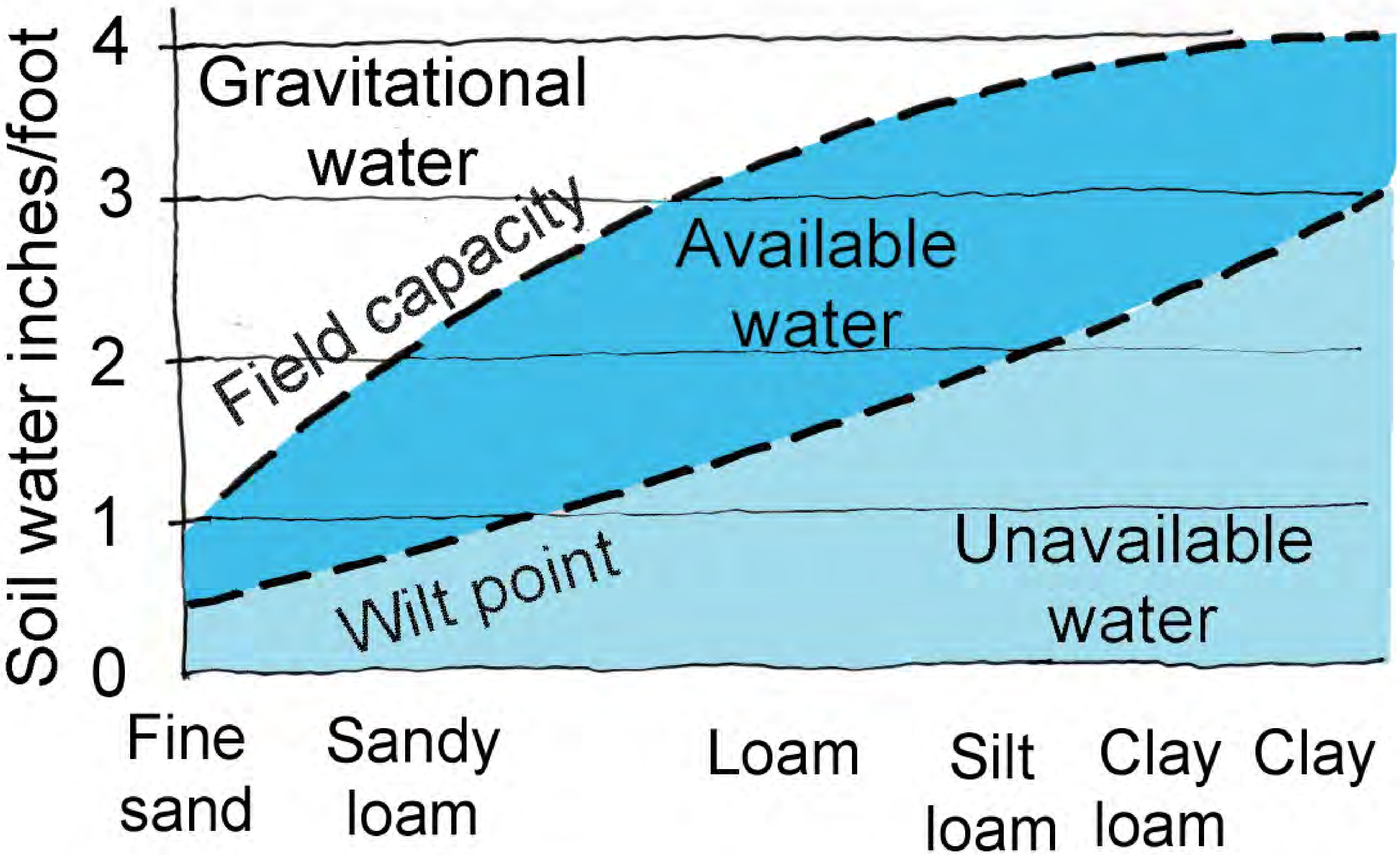
Field Capacity

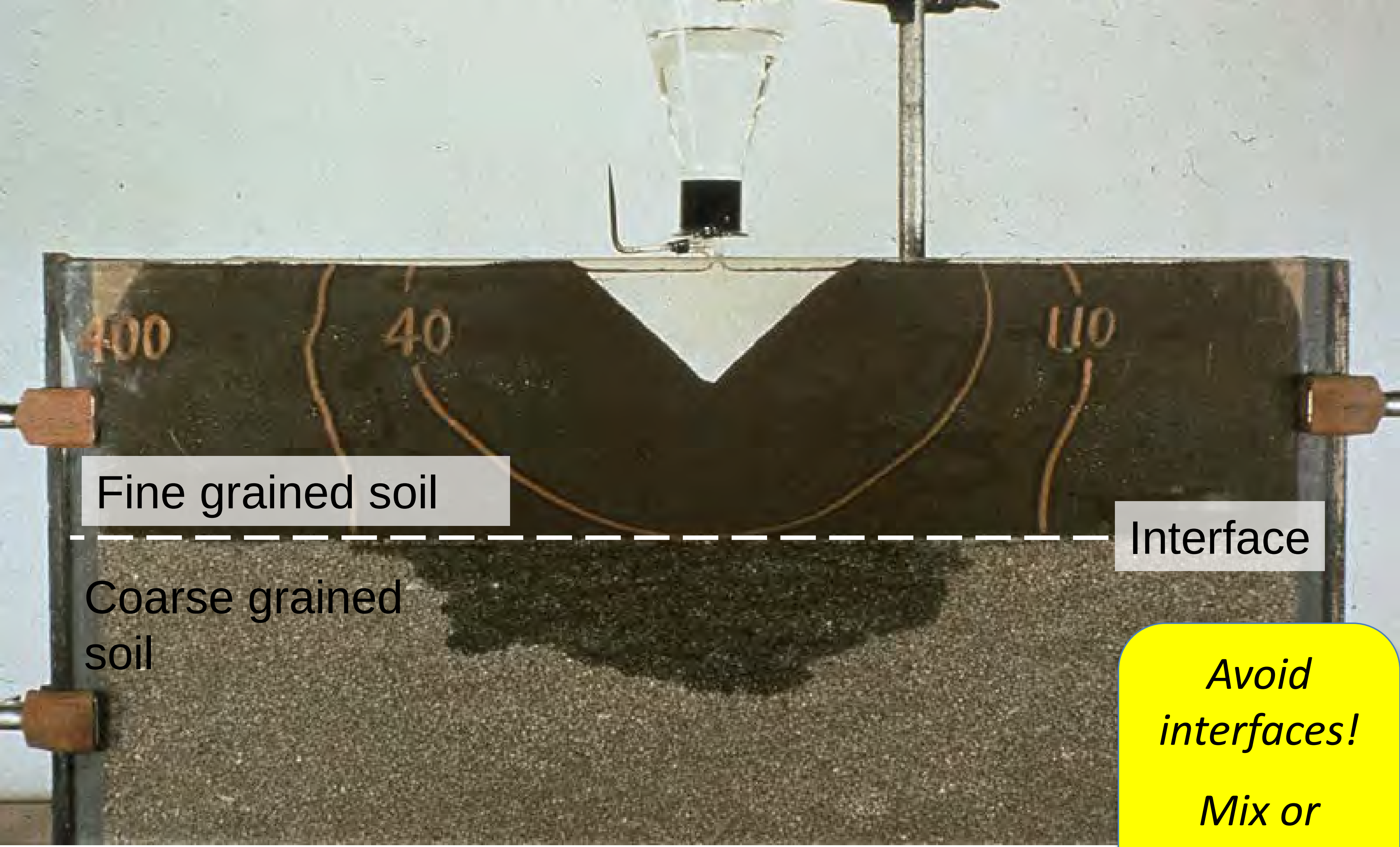
gravitational water has drained out



Wilt Point

remaining water held in micro-pores too tightly for plants to suck it out


Soil water inches/foot
4
3
2
1
0
Gravitational
water
Field capacity
Available
water
Wilt point
Unavailable
water
Fine
sand
Sandy
loam
Loam
Silt
loam
Clay
loam
Clay

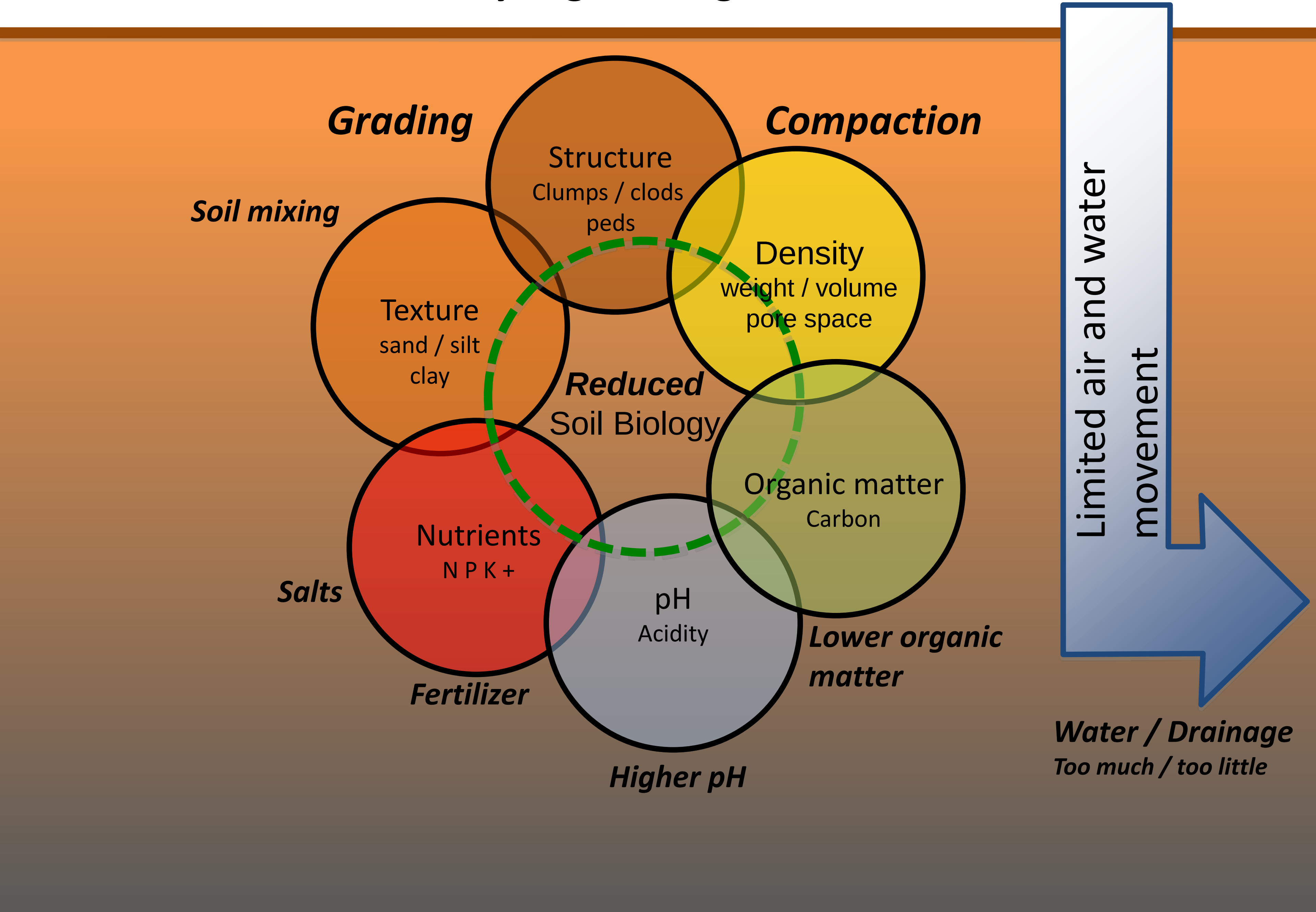


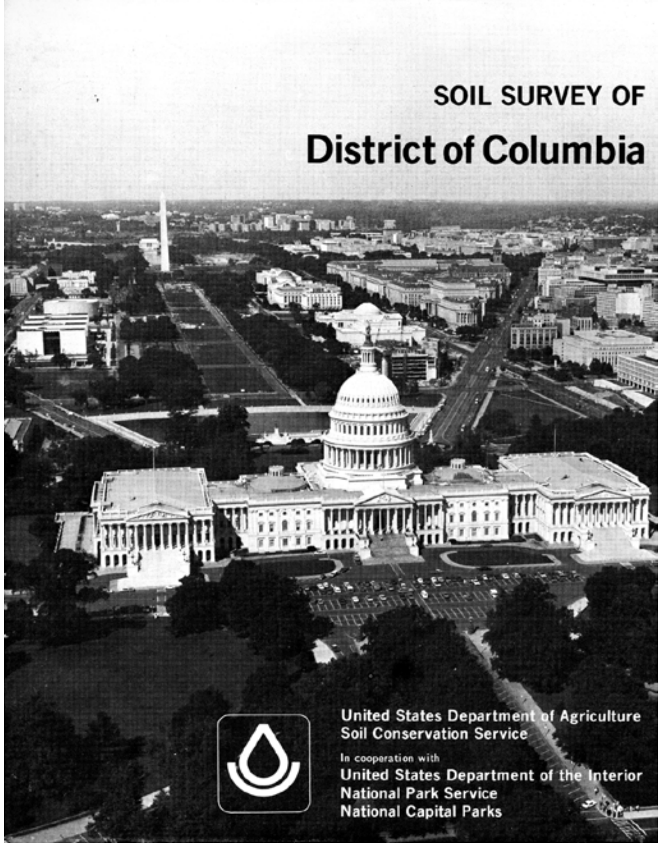
Soil interface slowing the flow of water
Upper layer must become saturated before water moves into lower layer

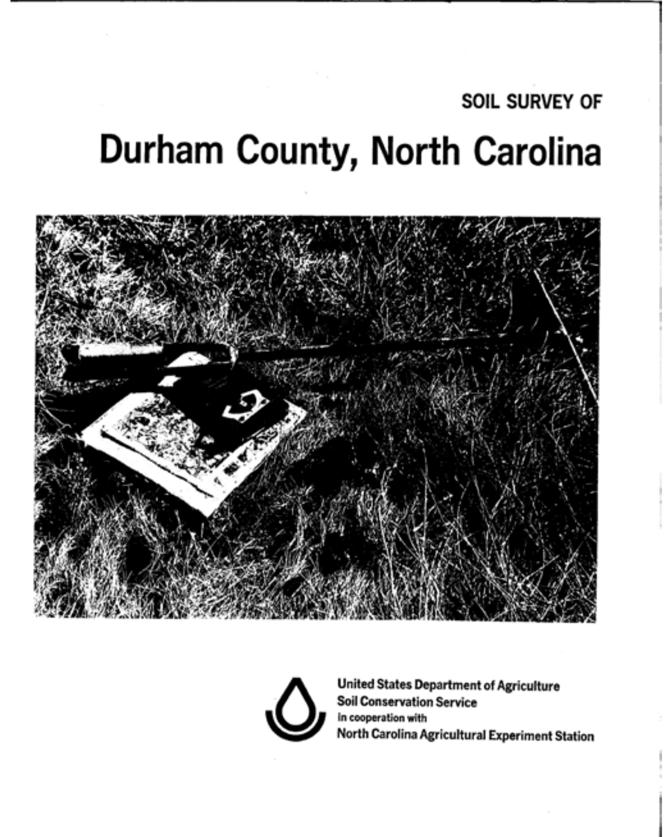
Avoid interfaces!

Mix or scarify soil layers

Analyzing Existing Site Soil







USDA Soil Surveys: *a good starting point, but use with caution!*

⇒ Compare site soil to the existing USDA survey description:

- Changes since development
- Consistency with existing conditions
- Graded and compacted conditions
- Imported soils

Limitations of traditional soil analysis methods for disturbed urban soils

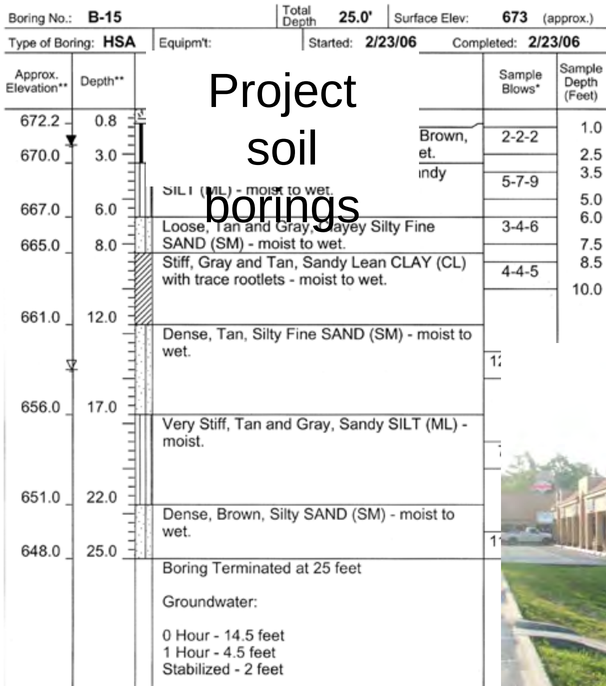
- Soils vary across site: fill?, native? Subsoil?
- Mixed or missing horizons – topsoil layer often removed
- Sharp interface problems (between native and fill soils)
- Compaction
- Low ph, anaerobic?
- Low organic matter
- Debris, toxins?



Jim Urban's *Real* Soil Classifications

	Sort of Bad	Good	Real bad
Drainage	Excessive Dry	Moist but well drained	Excessively Wet
Compaction	Very Loose	Consolidated or Aggregated	Very Compacted
Organic Content	Greater than 10% or less than 2%	2-3%	0.5 - 0%
Texture	High sand	Loam	High Clay or Silt
Fertility Indicators	high or Low	Just Right	Very high or low
pH	Below 5.5	6.0 to 7.5	Above 8.5 or Below 5

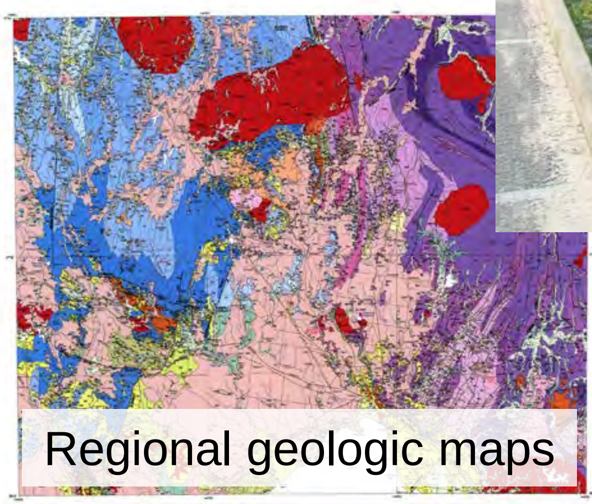
Non traditional ways to survey urban soil



Project soil borings

Old maps and photos

Read existing topography



Regional geologic maps

Interviews

Plants as indicators of soil differences and problems


Stressed tree
Poor soil
Healthy tree
Good soil

WSDOT

I-5 Marvin Rd. Interchange

Compost

Which site is selling the next job?

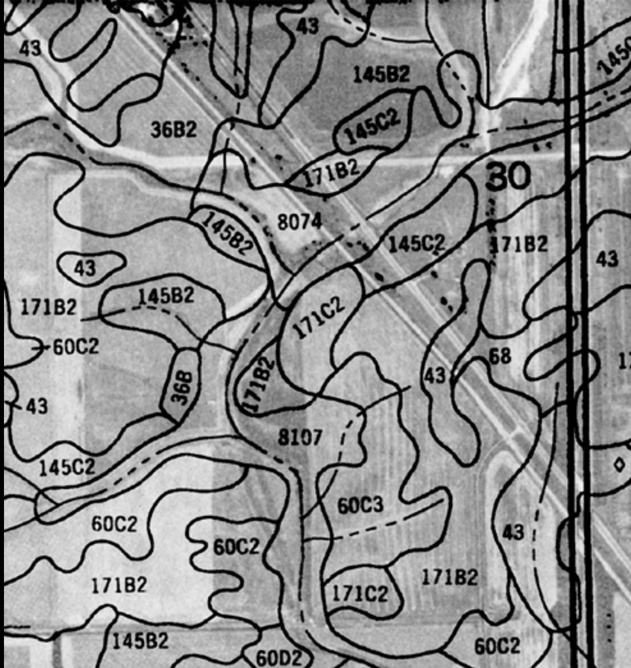
Which needs more water, fertilizer, weed control?

No Compost

UW trials: up to 50% reduction in storm water runoff when glacial till soil is amended with compost.



Adjacent constructions can reveal soil types and issues



Find a reference soil in or near the site that might be undisturbed.

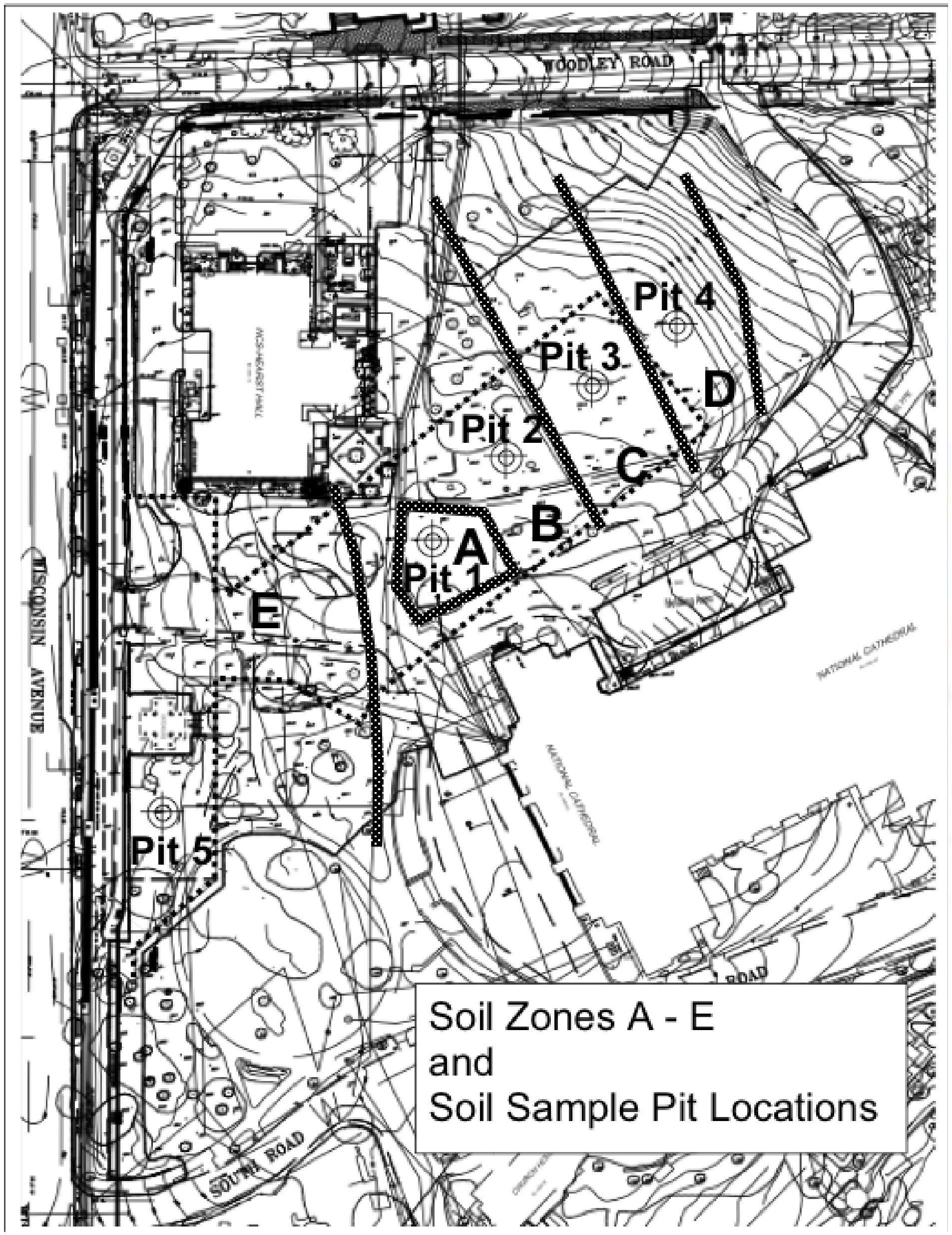
Under old trees, at property lines, cemeteries, parks etc.

Use this to find remnant soils.

Constantly smell the soil! Sour odor indicates poor drainage

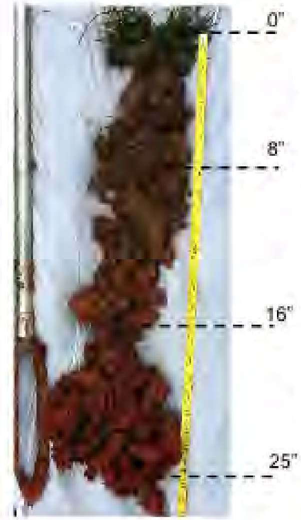
Grey color, poorly draining soil

Washington Cathedral
Surface Soil Investigation
July 25, 2005



Washington Cathedral
Surface Soil Investigation
July 25, 2005

Pit 3 - Soil Zone C: Good quality lawn, no trees. Soil is poorly drained but not anaerobic.



A Horizon - Brown clay loam topsoil, moist, little humic odor.

B/C Horizon - Orange brown clay transition between A and C horizons, moist to wet, no humic odor

C Horizon - Orange clay, sharp change in firmness at 17" due to dryer soil condition.

Soil test results and evaluations:

Pit 3 - A horizon: Clay loam soil. low pH (5.8)
This soil is similar to the topsoil found in zone and D. These topsoils are usable as deep soils for trees and for lawns that are not expected to have significant compaction forces or as a base material for sand/soil mix for compaction resistant lawn

Pit 3 – B/C horizon: Clay.
This soil could be a useful base to mix with sand and compost in areas of trees, shrubs and or lawns.

Pit 3 - C horizon: Soil determined at field evaluation to have too much clay and too compacted to be useful.

Make a soil survey map

Record all the information on a drawing to show the different soil types and soil issues

Resources to learn more:

WSU Soil Management

www.puyallup.wsu.edu/soilmgmt/Soils.html see videos and factsheets on "Collecting a soil sample", " "Determining soil texture by hand", "Understanding soil tests"; plus more info for gardeners at www.puyallup.wsu.edu/soilmgmt/Gardening.html

Building Soil Manual: construction best practices

www.BuildingSoil.org or www.SoilsforSalmon.org

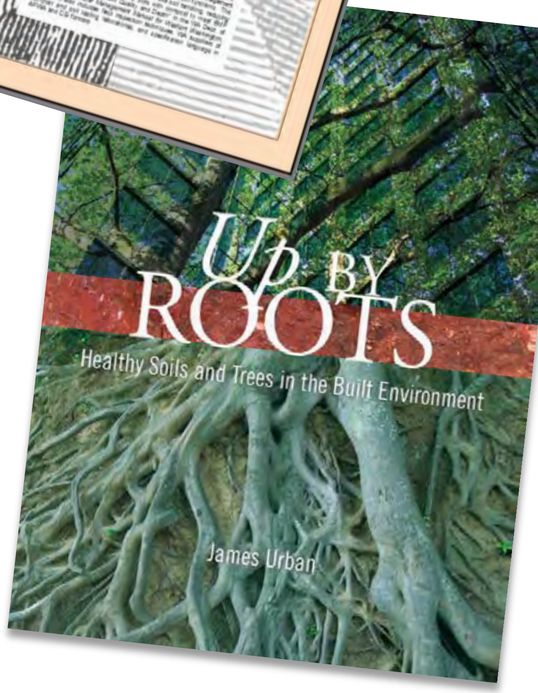
Low Impact Development Manual for Puget Sound

http://www.psp.wa.gov/LID_manual.php

Soil Biology Primer

http://soils.usda.gov/sqi/concepts/soil_biology/biology.html

Up by Roots: by James Urban: practical soil science and strategies for successful urban landscapes *(available on Amazon)*



Discussion Question:

How do you assess the soil and drainage of a site prior to designing the landscape.