Healthy Soils – Part 1:
Soil Science for Sustainable Landscapes

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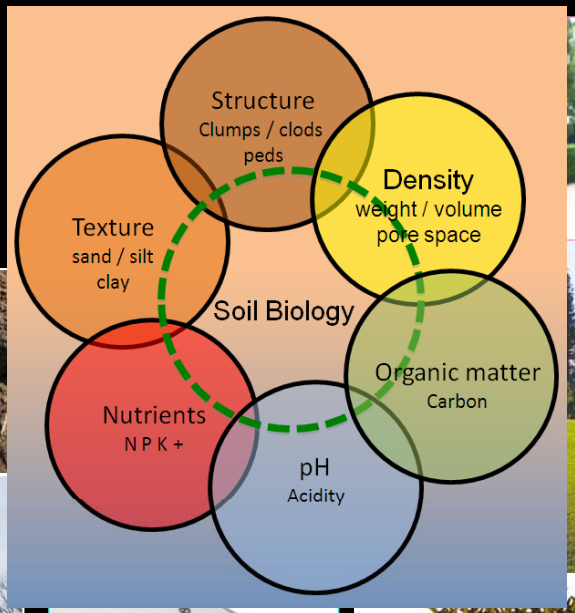
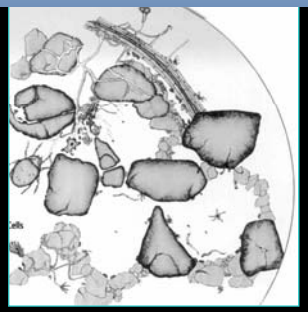
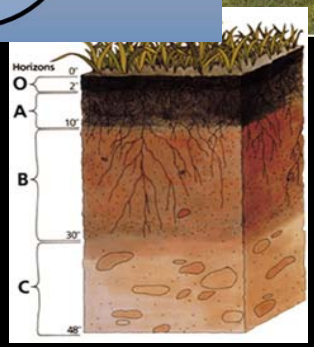
With slides from
James Urban, FASLA, ISA
Urban Tree + Soils





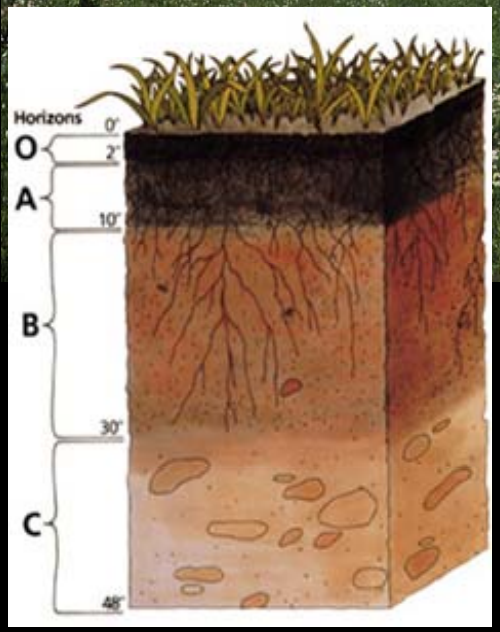


Based on Healthy Soils Part 1 and Healthy Soils Part 2 by James Urban and David McDonald from ASLA conference Phoenix 9/6/2012, and Soil Improvement for Stormwater, Erosion, & Landscape Success by David McDonald from WSU Low Impact Development course 4/11/2012

www.SoilsforSalmon.org
www.BuildingSoil.org

Natural soils vs. Disturbed urban soils

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

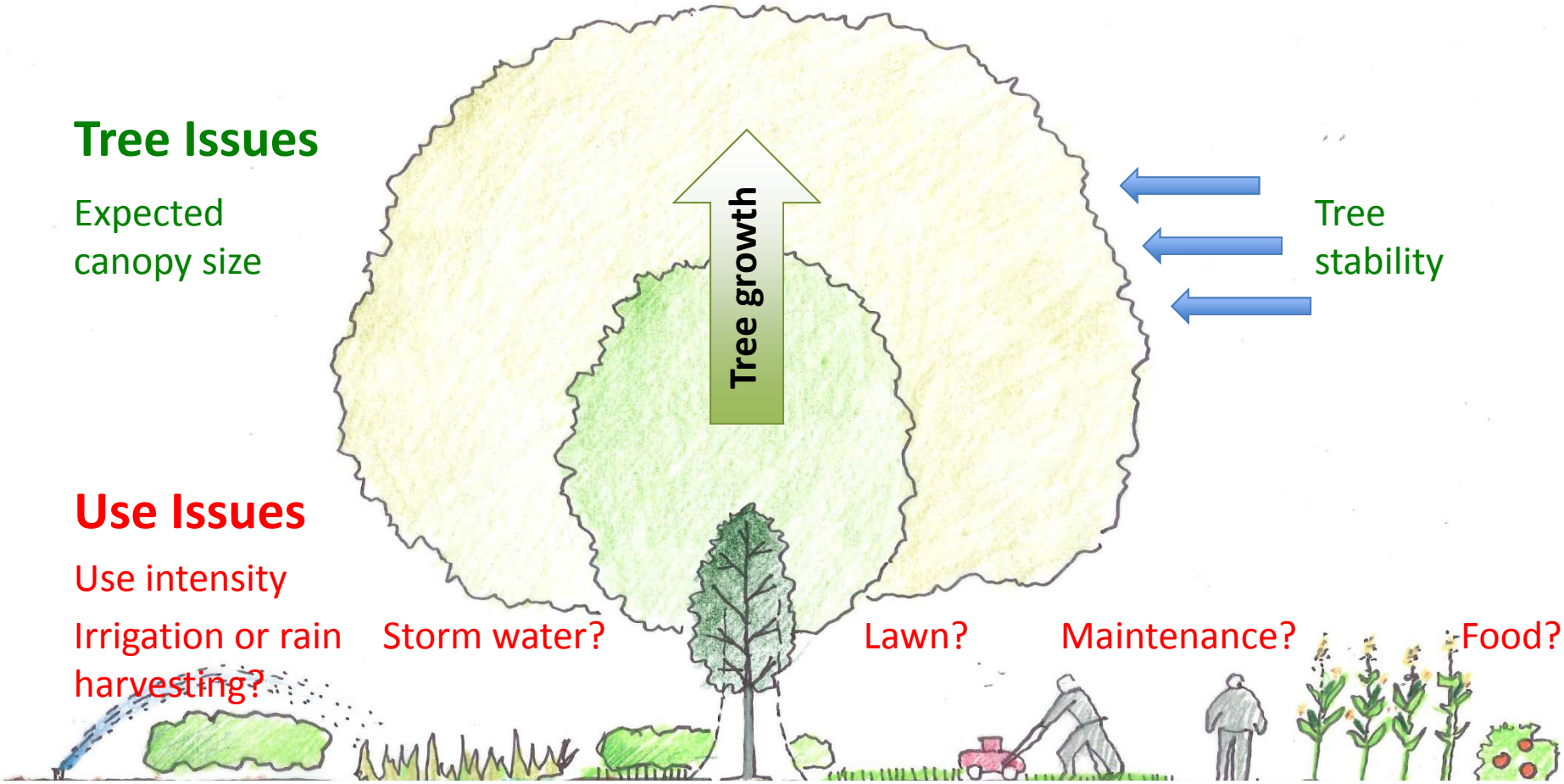


- Vary across site
- Topsoil layer removed
- Compaction, low OM
- Subsoil (or worse) fill layers
- Debris, toxins?

Soil Goals and Requirements

Tree Issues

Expected canopy size



Soil Issues

Soil drainage

Space for roots and trunk flare

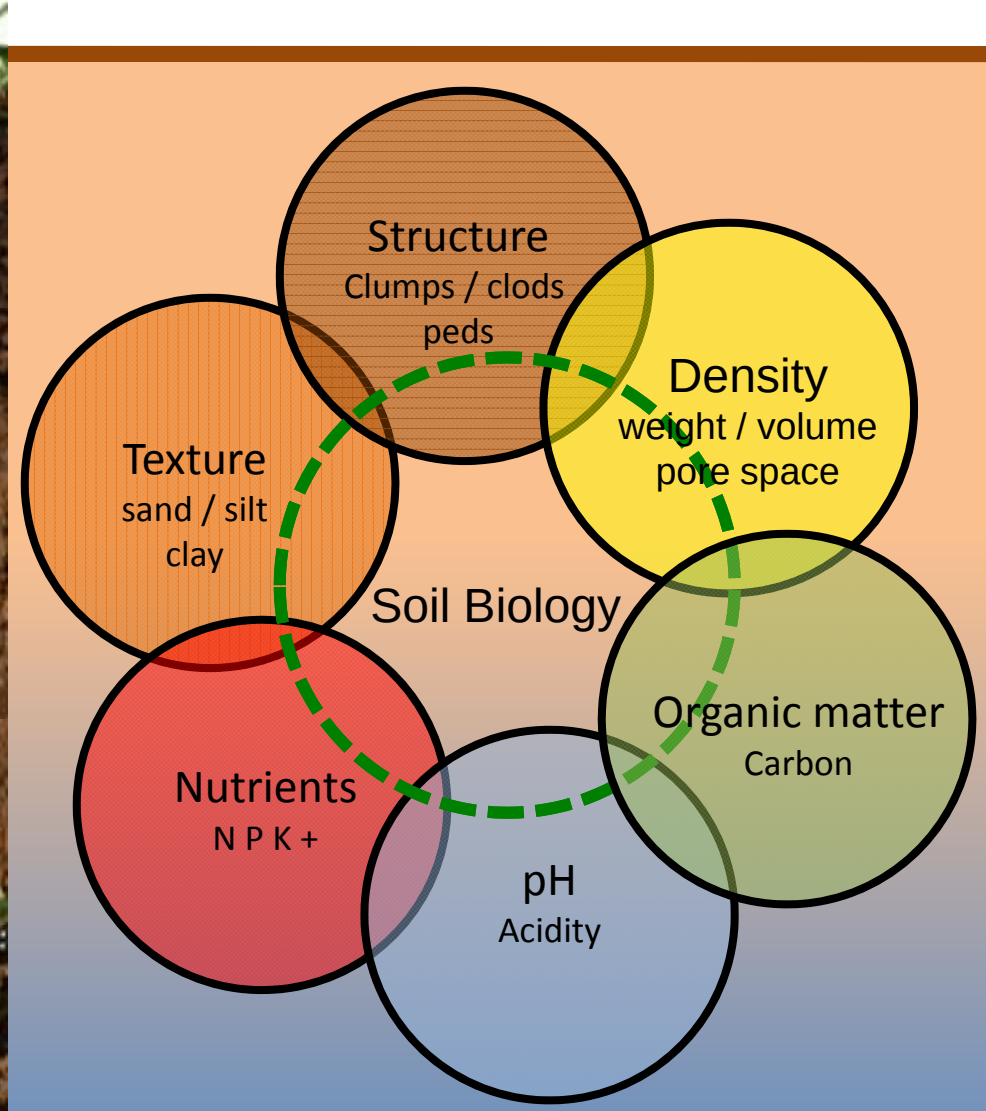
Sufficient soil volume

Imported soil sources

Existing soil conditions

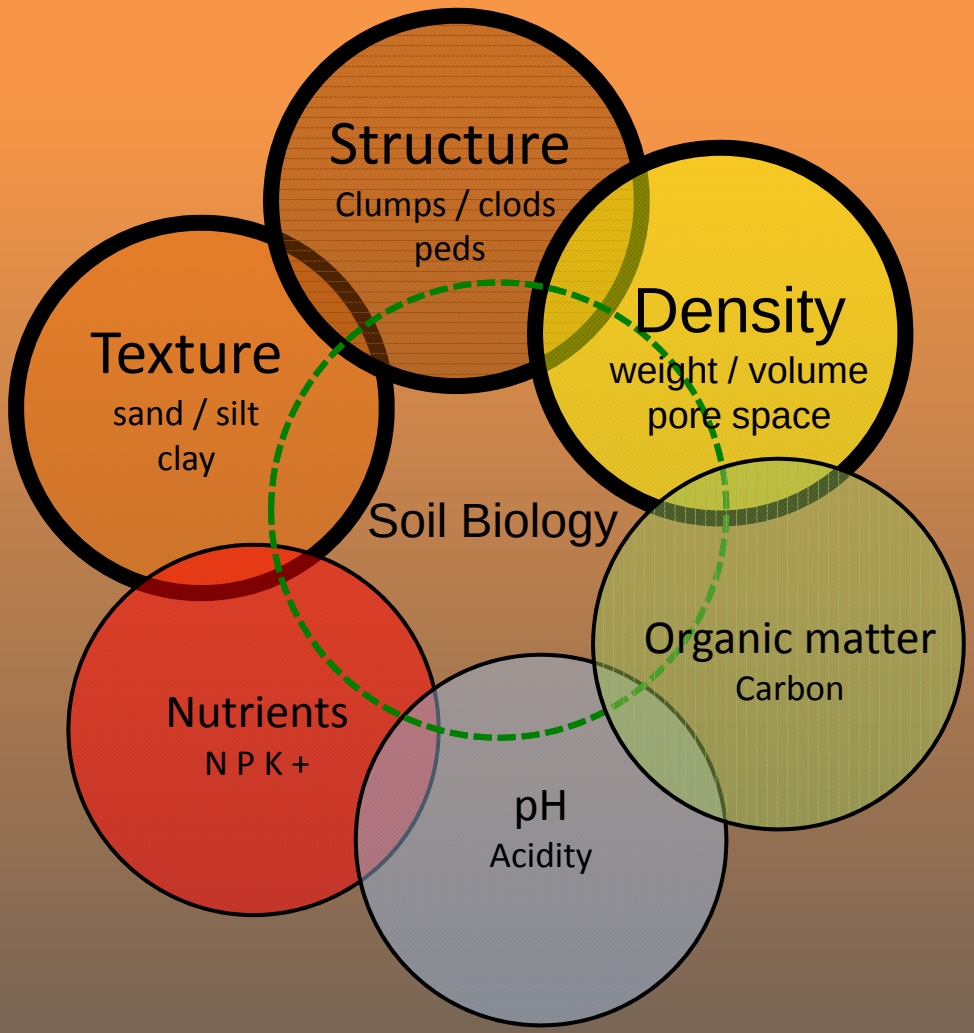
Grading

Critical Aspects of Soil



Air and water movement / soil profile

Physical properties of soil



Air and water movement / **Soil Profile**

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

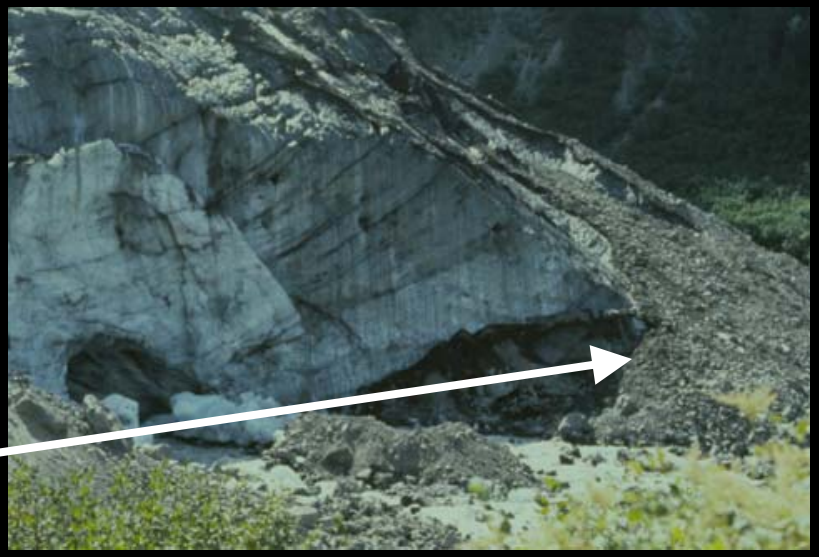
volcanic ash: light, fertile, holds moisture - mostly blown east of Cascades

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



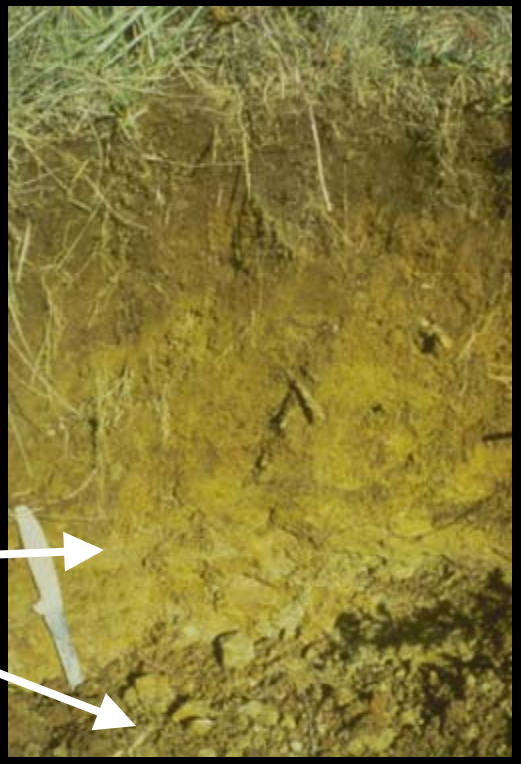
- *Basal till* from under the glacier (1/2 mile of ice over Seattle!) has been compressed into **hardpan**

- 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

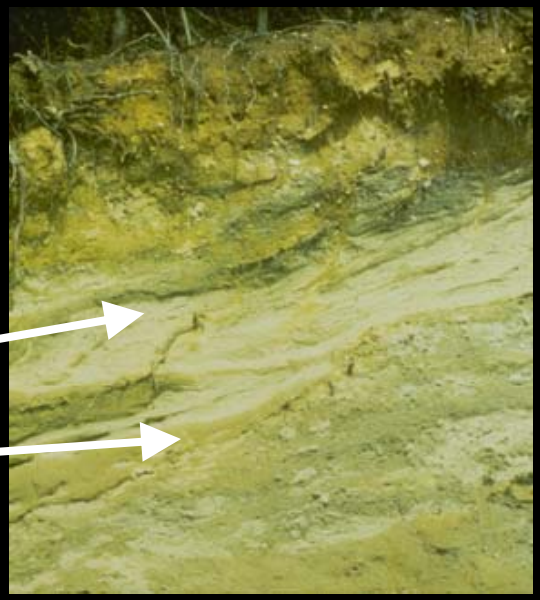
Alluvial soils

- 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!

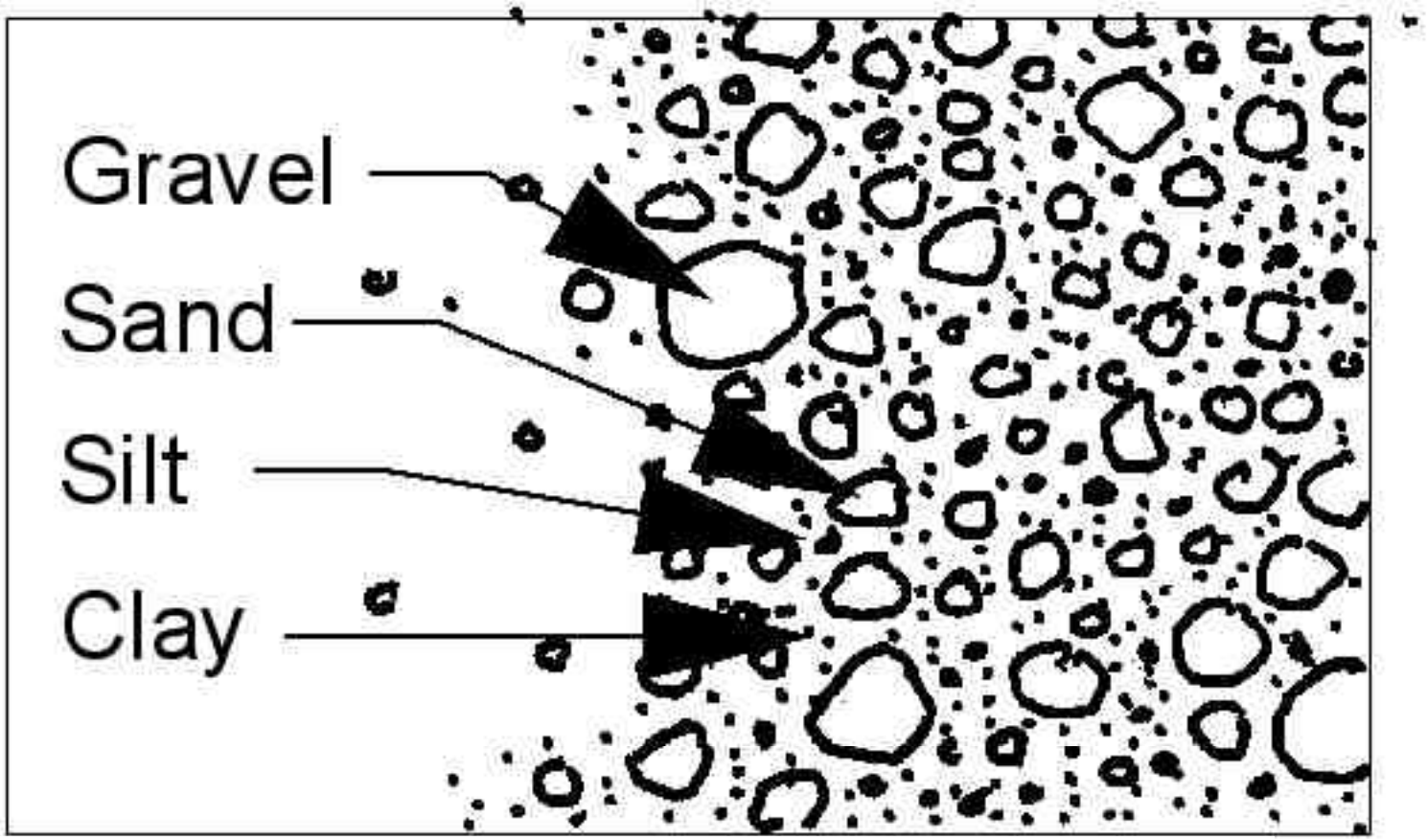
- Sandy outwash over compacted basal till hardpan
- Thin soil over bedrock
- Clay lenses over hardpan, or inter-layered with sand (unstable!)



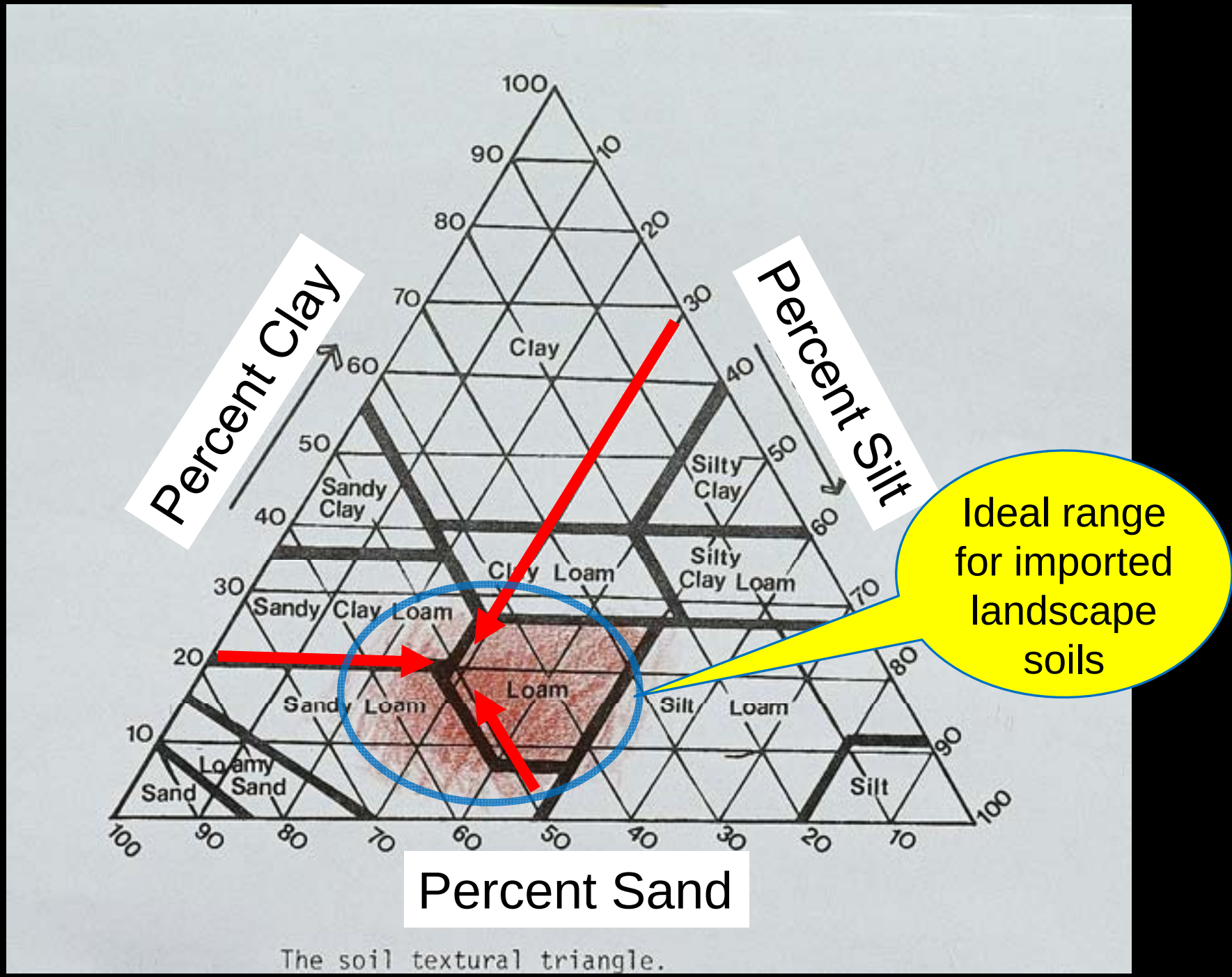
Soil formation -Human forces

Disturbed soils in urban areas

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



Soil Texture (= particle size)



The soil textural triangle.

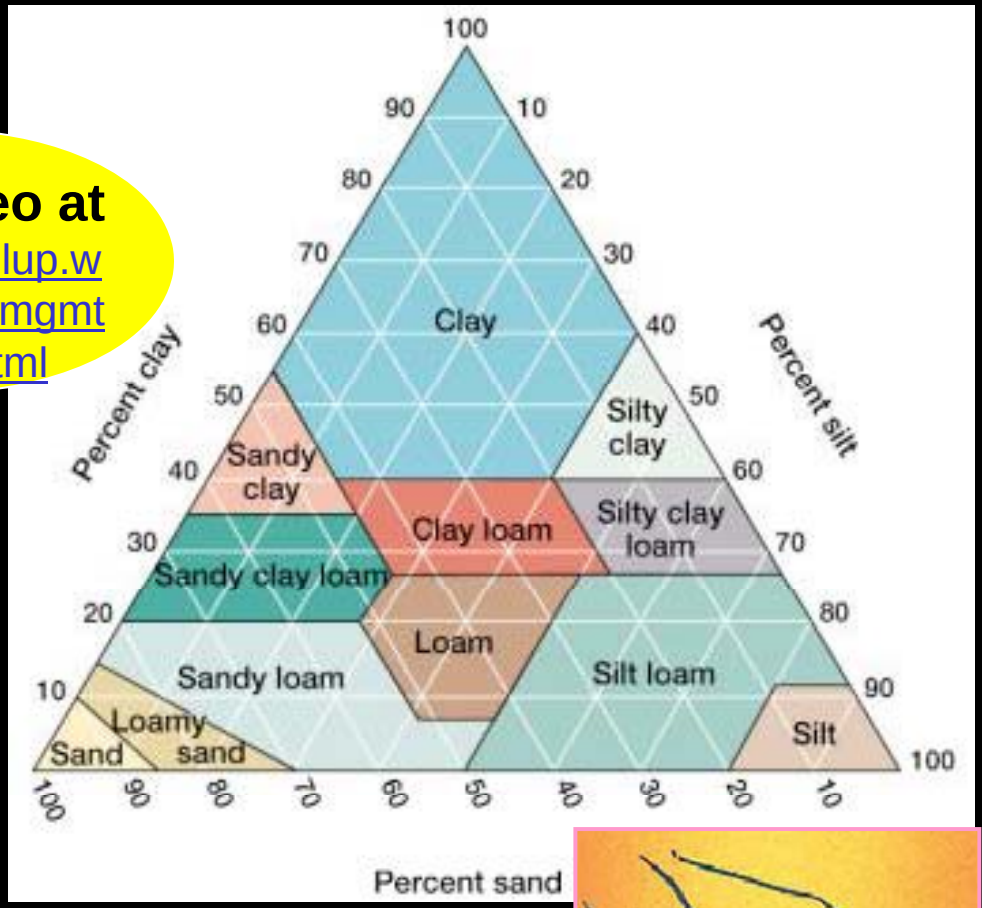
Soil Texture Test

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

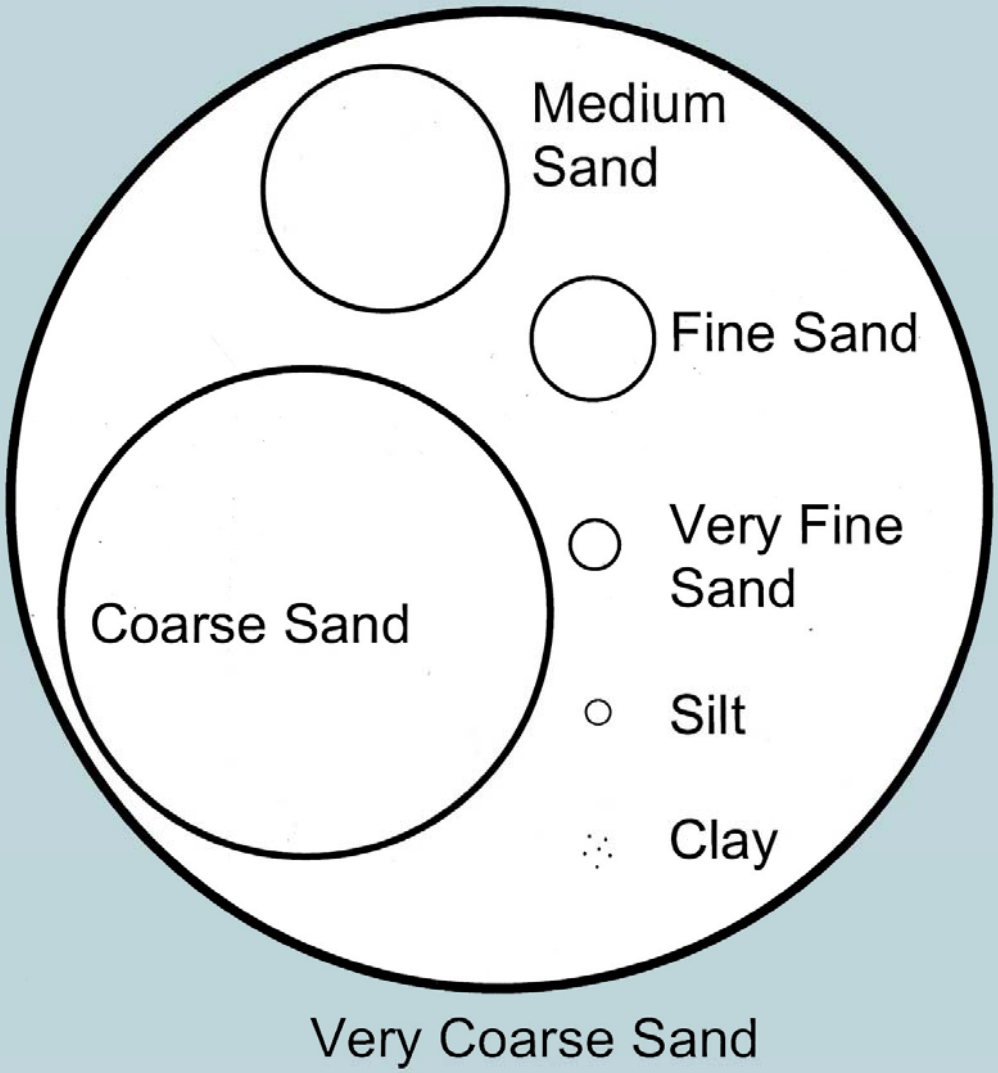
Ribbon+feel test:

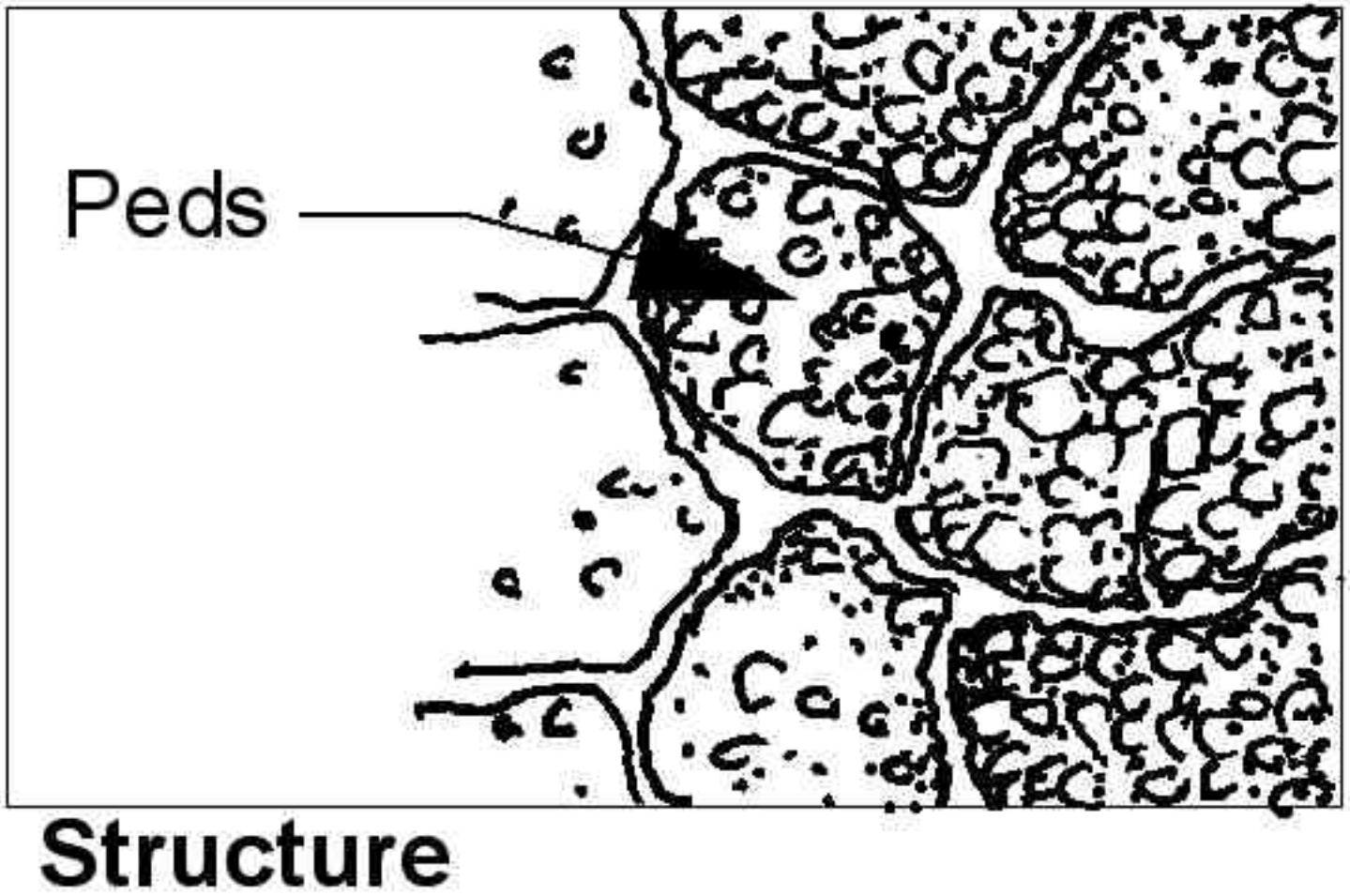
Moisten soil, roll between hands, then squeeze out with thumb:

- 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

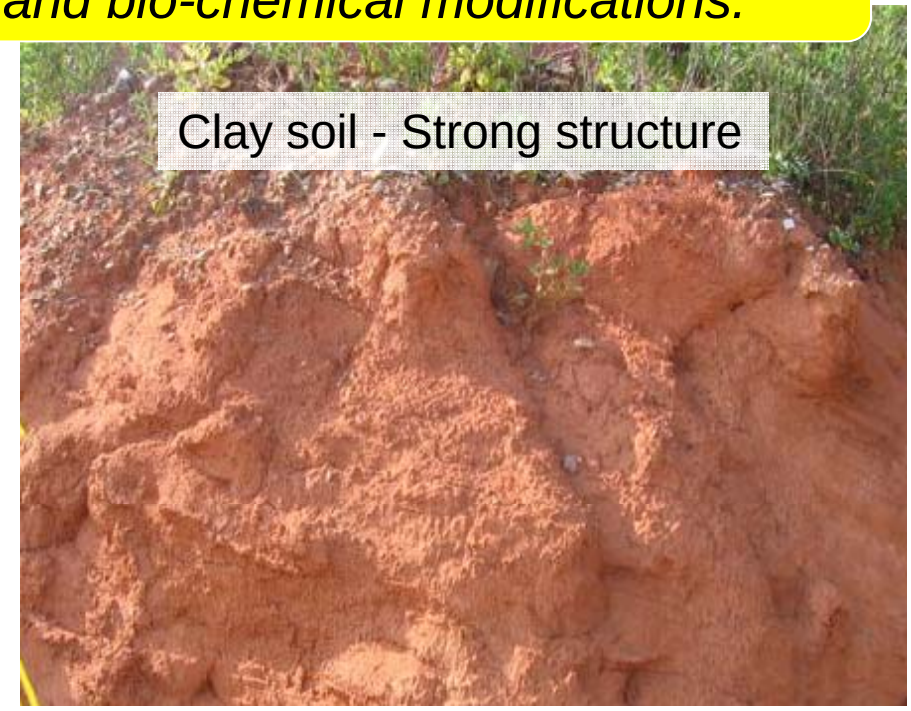




Structure

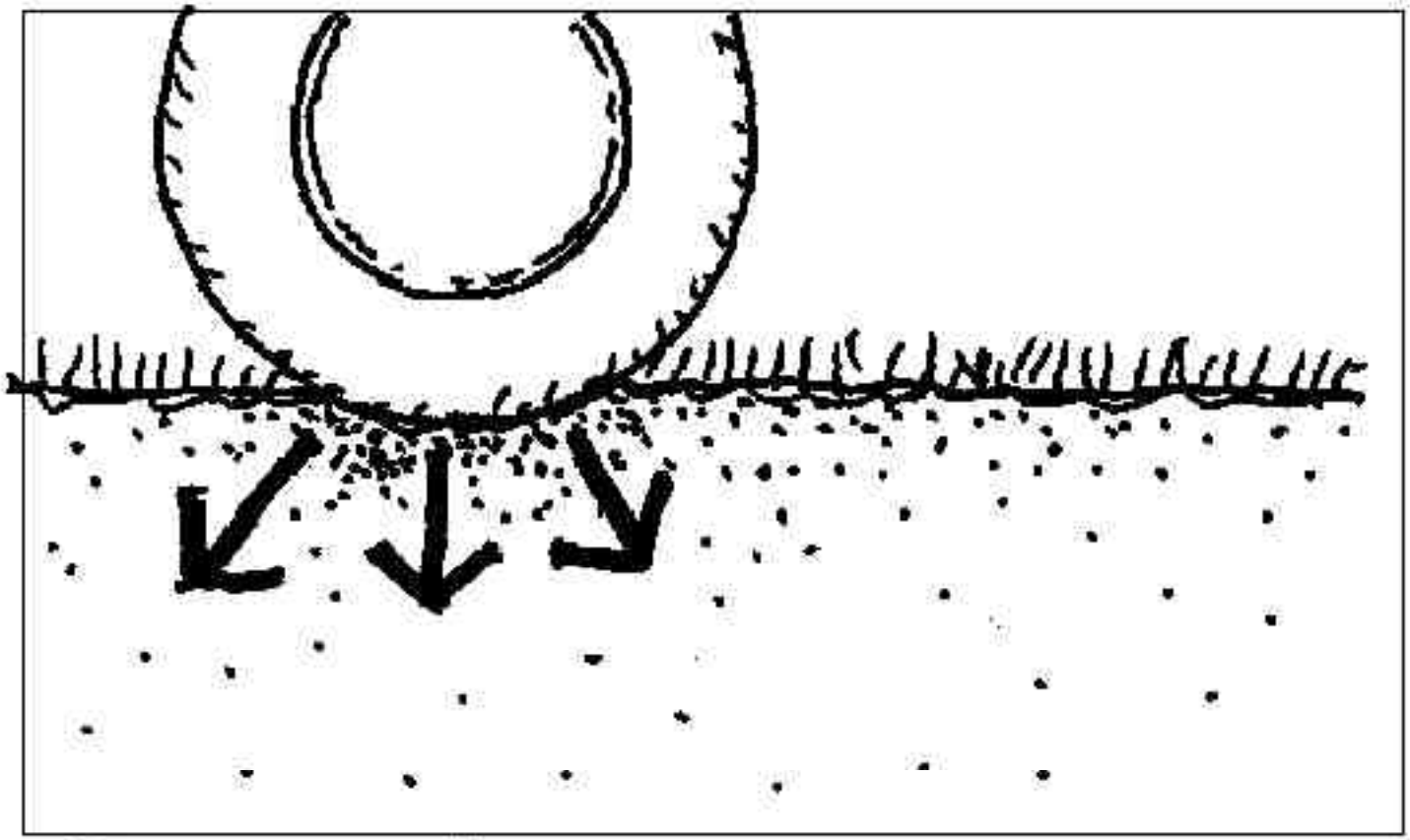
Don’t grind up your soil! Mix loosely to preserve the peds.

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

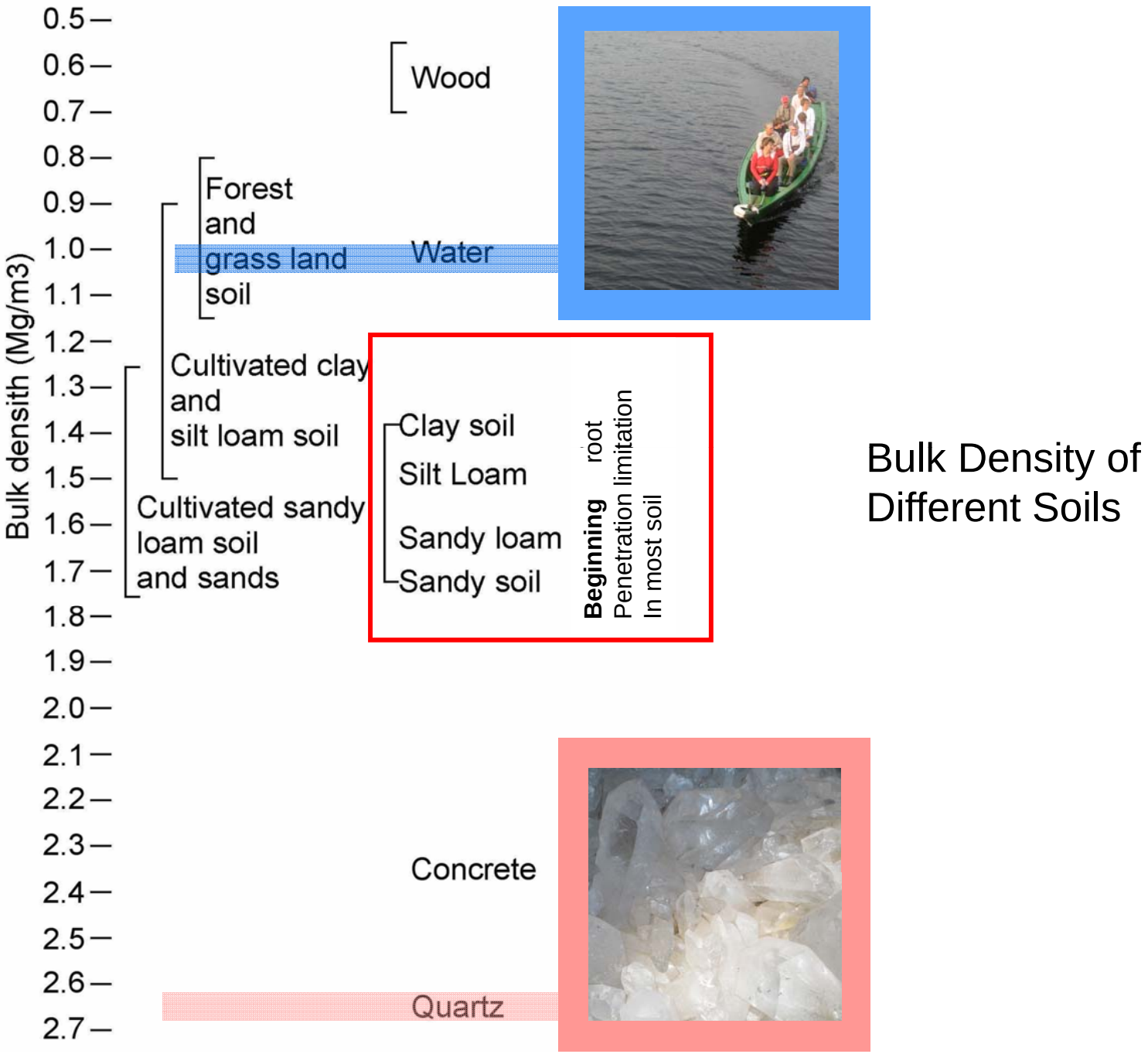


Sandy Loam Topsoil

Sandy Clay Loam Topsoil



Density or Compaction

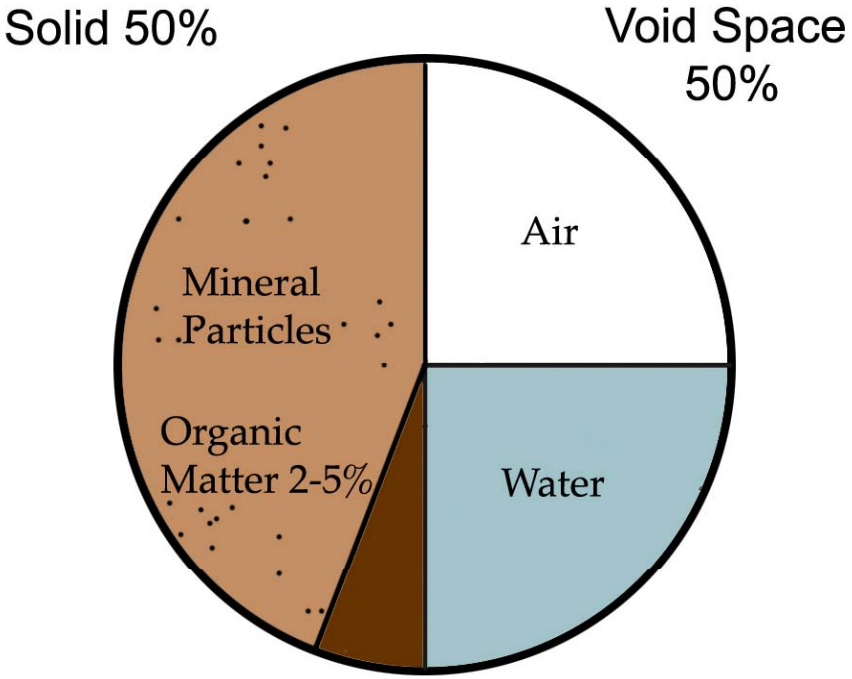


Bulk Density of Different Soils

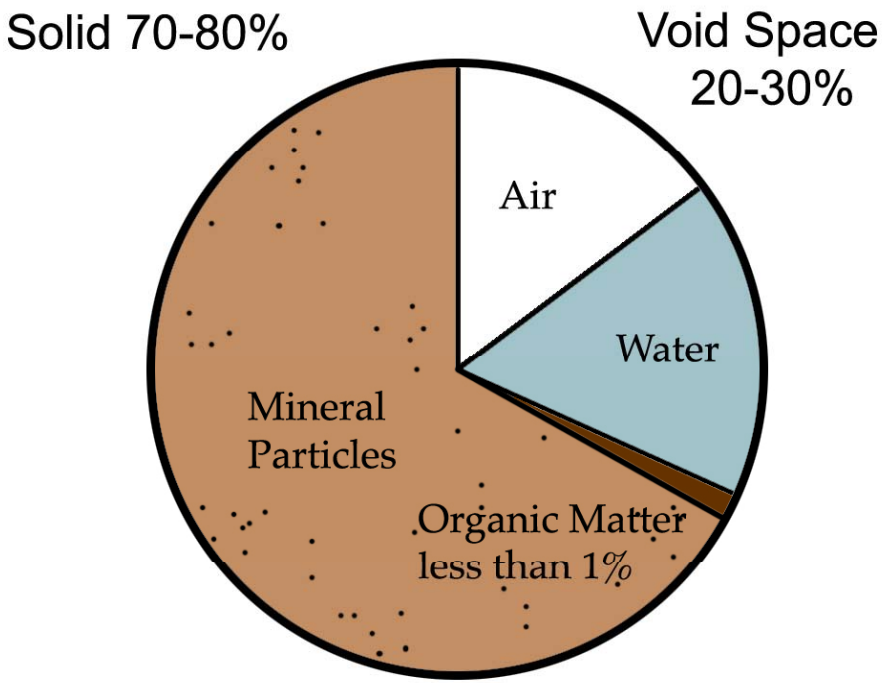
Bulk densities of soil mixes are different for similar natural soil textures.

Compost is very light, while **sand** and **lost structure** tends to make soil test heavier.

You have to test bulk density at a stated Proctor percentage.



IDEAL FOREST SOILS



URBAN SOILS

As compaction increases, pore space for water and air decreases

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

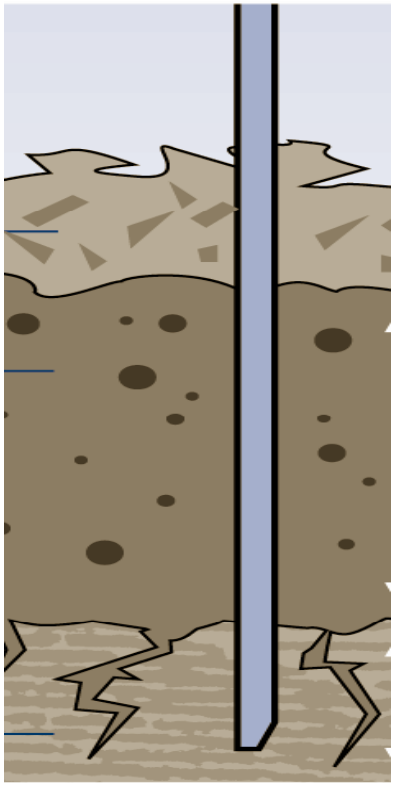
Fast less than one minute
Not very accurate
Soil moisture limited
Inexpensive
Anyone can operate

Units
Bulk density Lb/CF Dry weight

Bulk density cores

Slow one day
Accurate
Somewhat expensive
LA or soil service

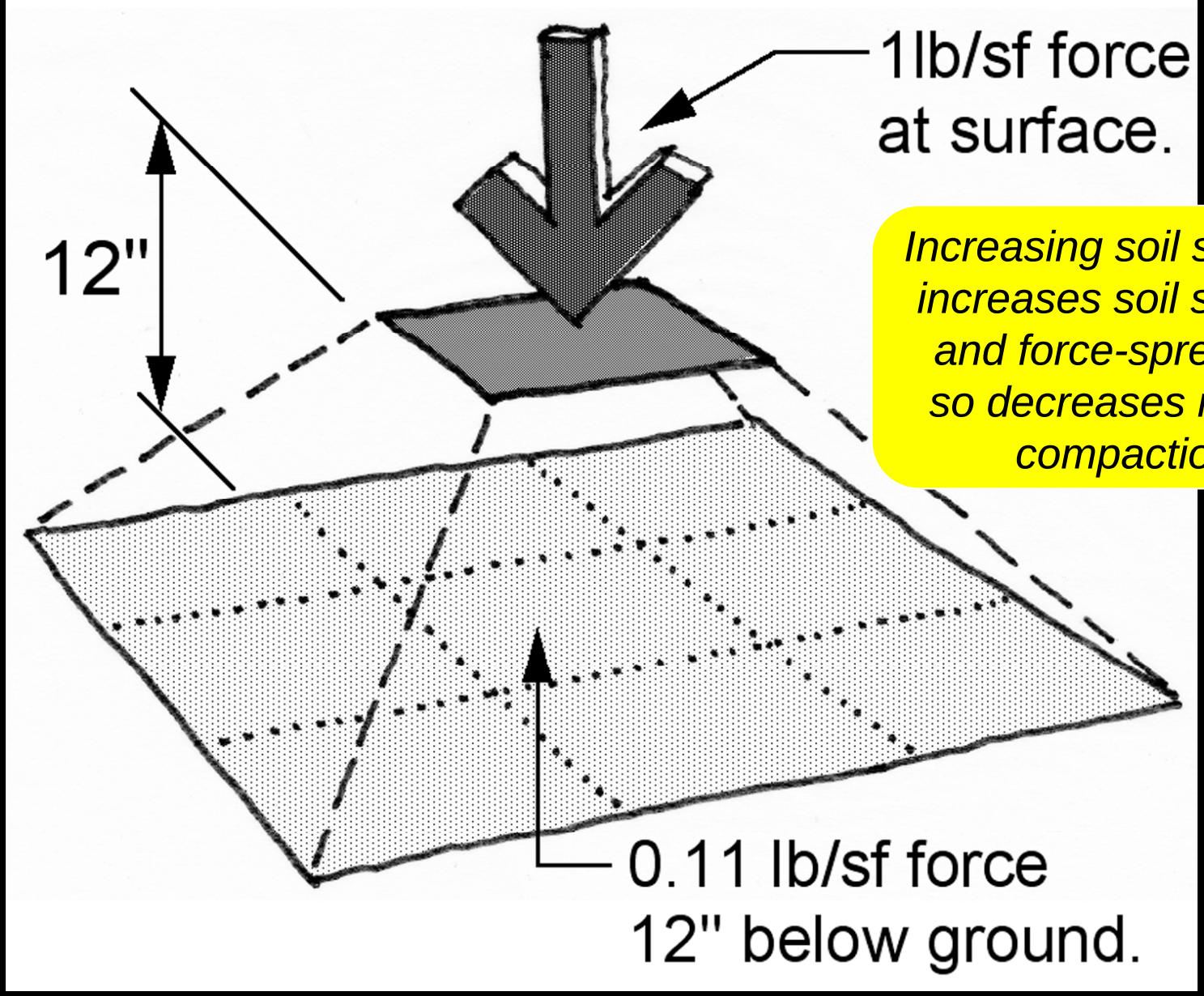
No Units
Comparative feel only



Rod penetrometer

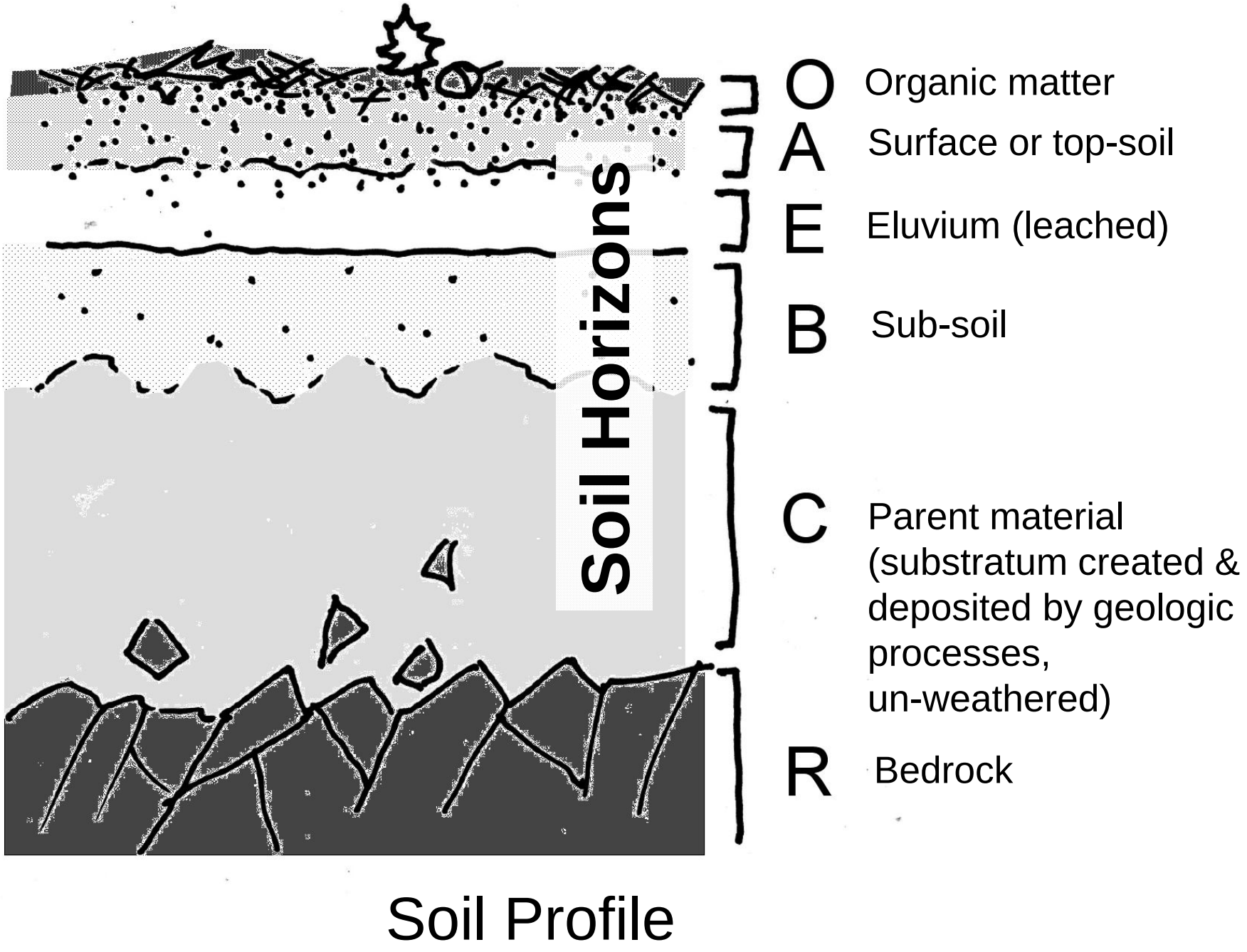
Inexpensive 3/8” bar with T-handle, driven by inspector’s weight:
Inaccurate, but gives comparative feel for compacted or uncompacted conditions

Soil Compaction Testing



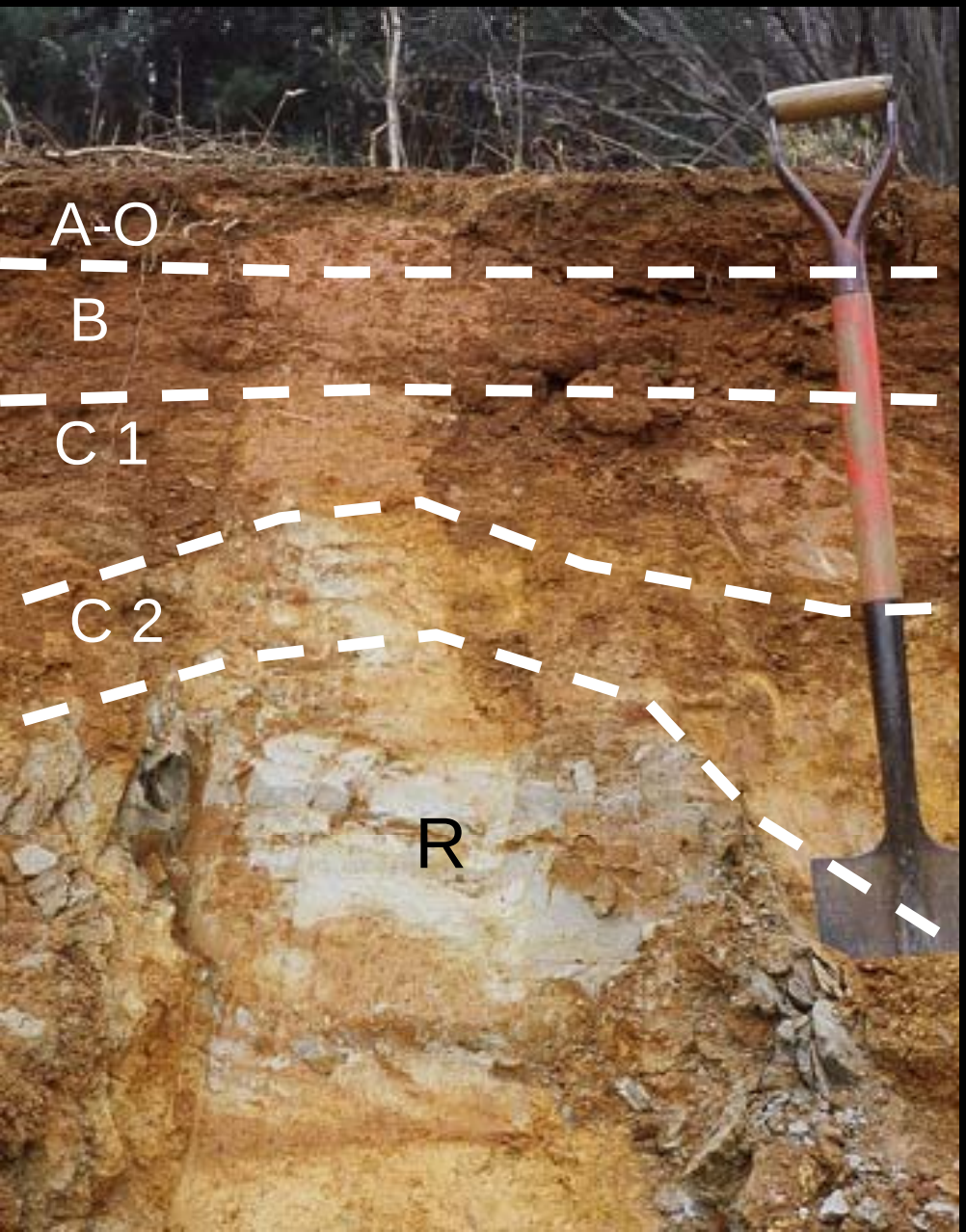
Increasing soil structure increases soil strength and force-spreading, so decreases net soil compaction.

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

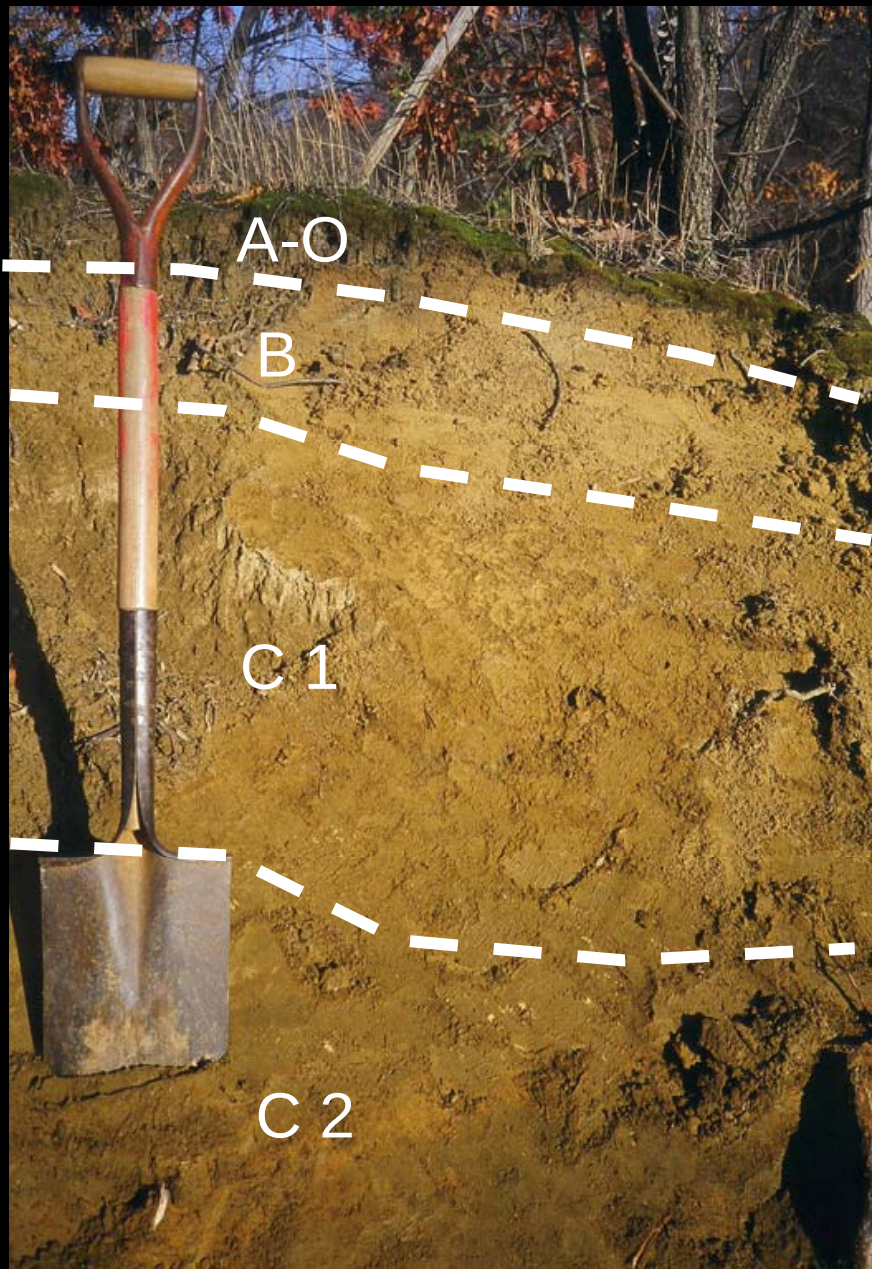


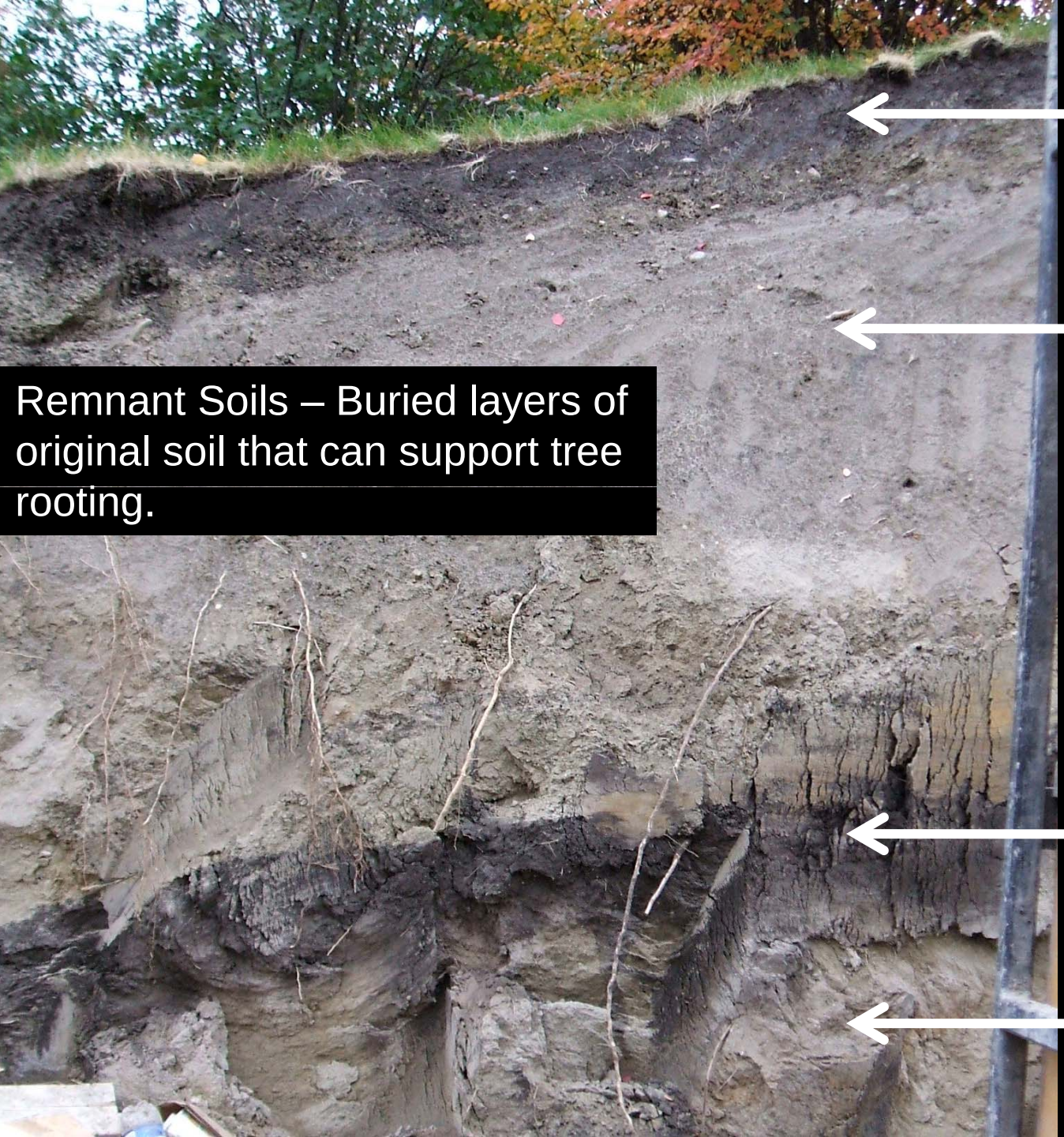
Soil Profile

Mountain soil

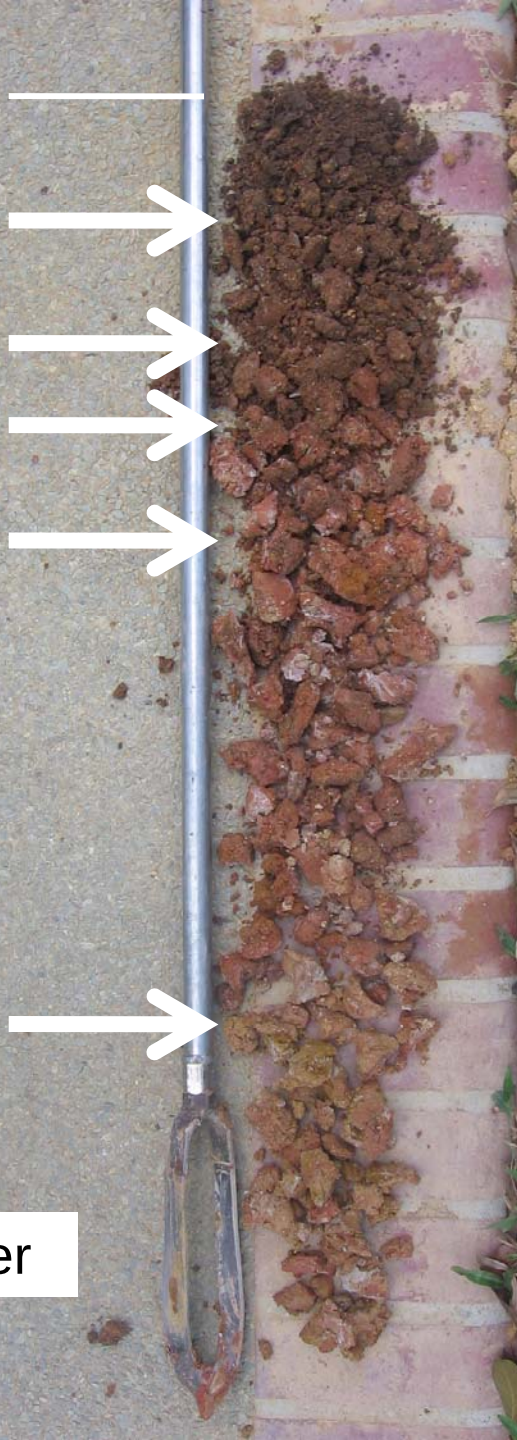


Coastal soil





Remnant Soils – Buried layers of original soil that can support tree rooting.



Changes in soil type

Examining a soil profile with a Dutch soil auger

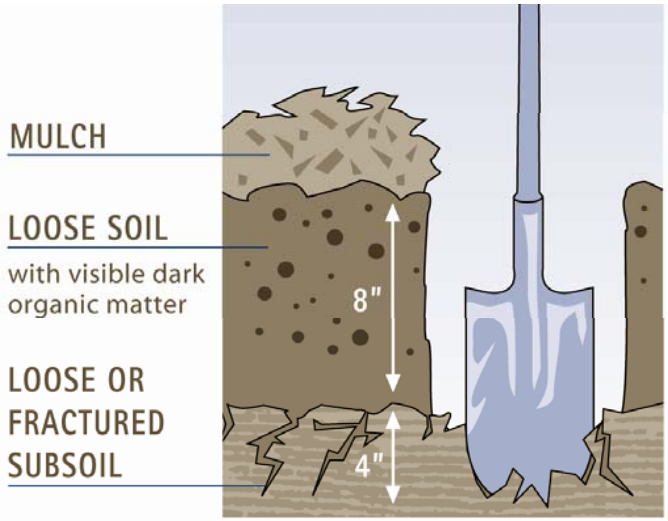
Examining a soil profile with a soil probe / core sampler

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

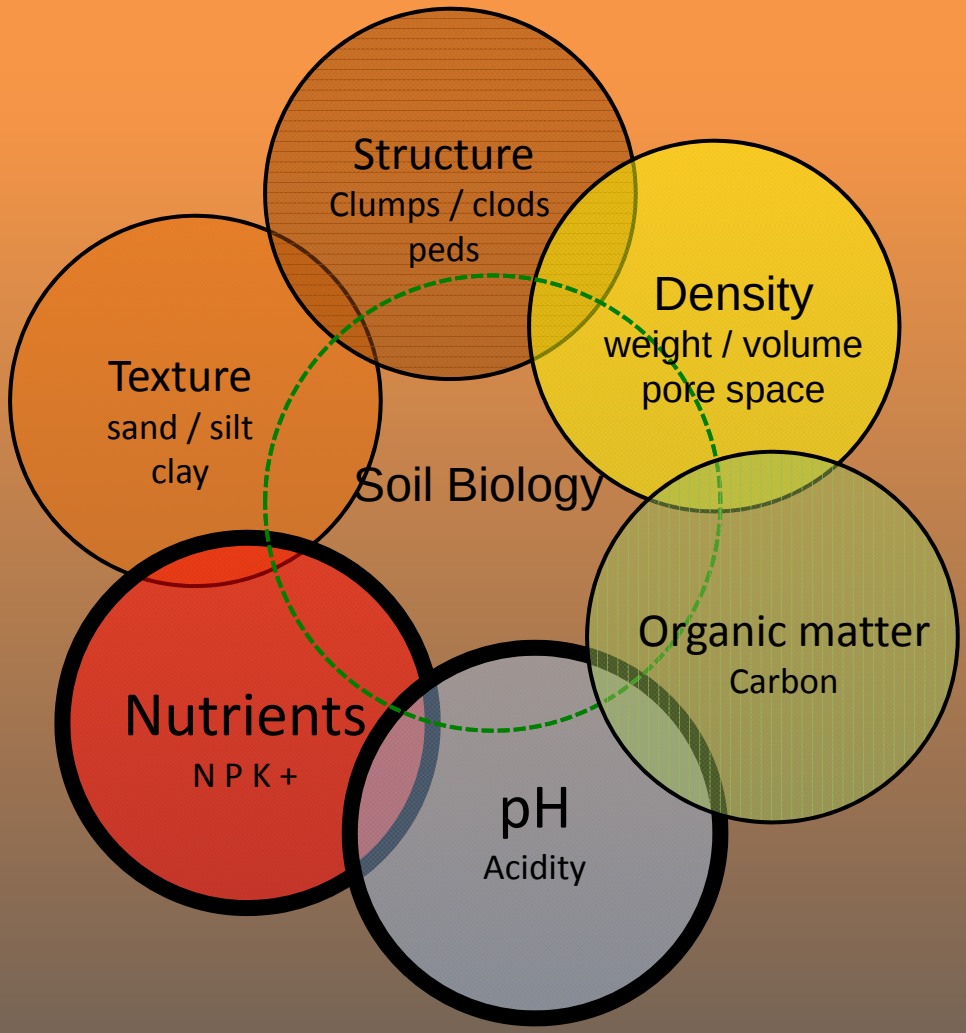
Compacted vs. Amended

Examining soil profile with shovel

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

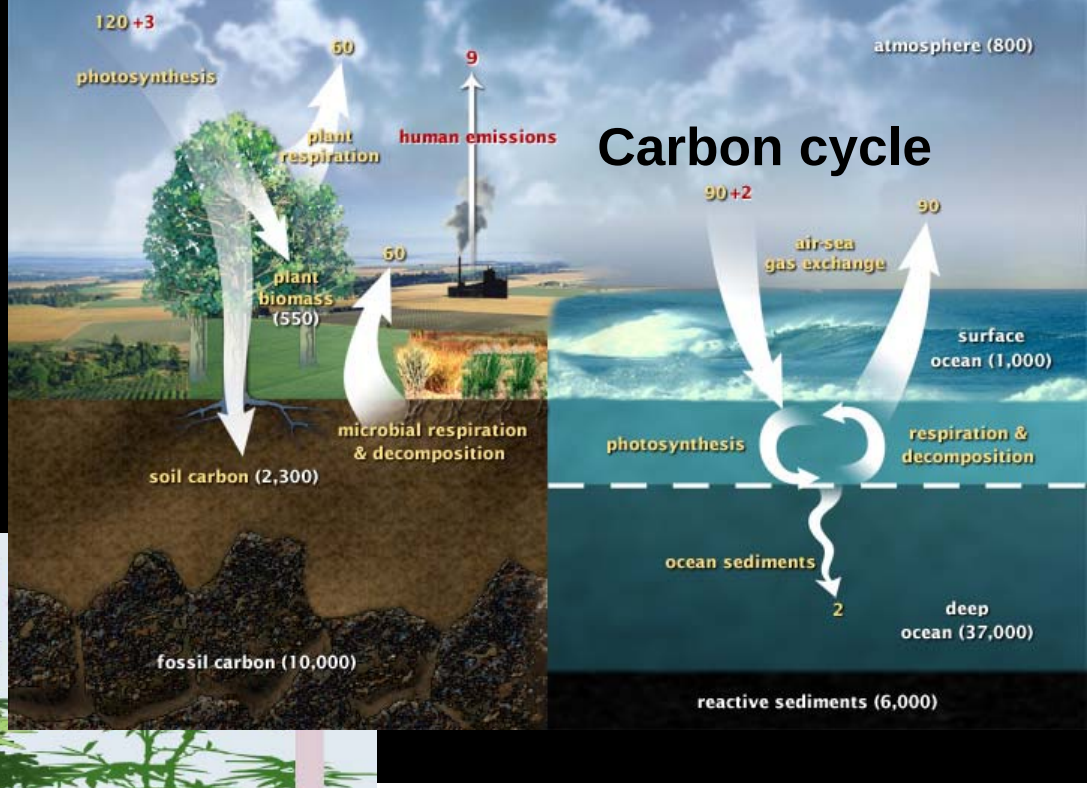


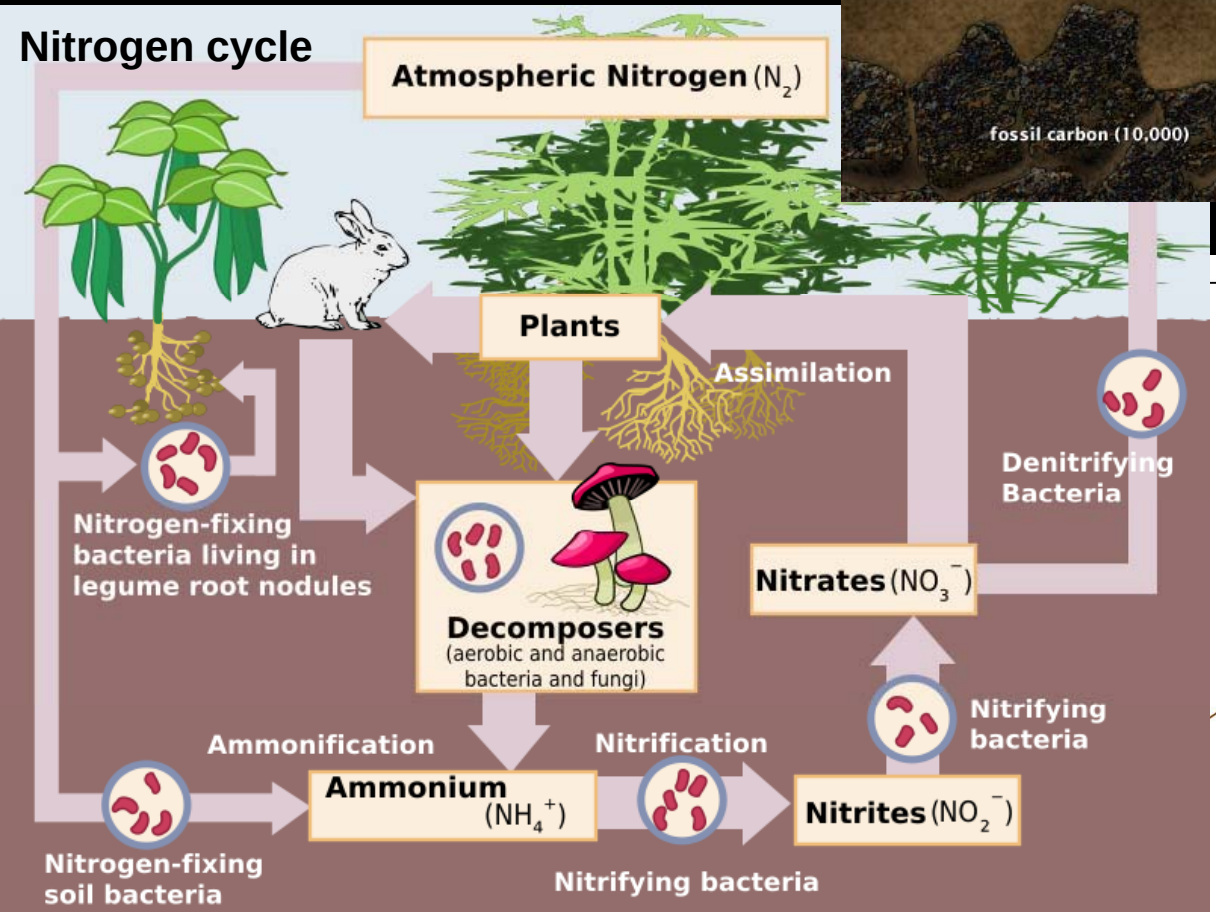
Chemical properties of soil

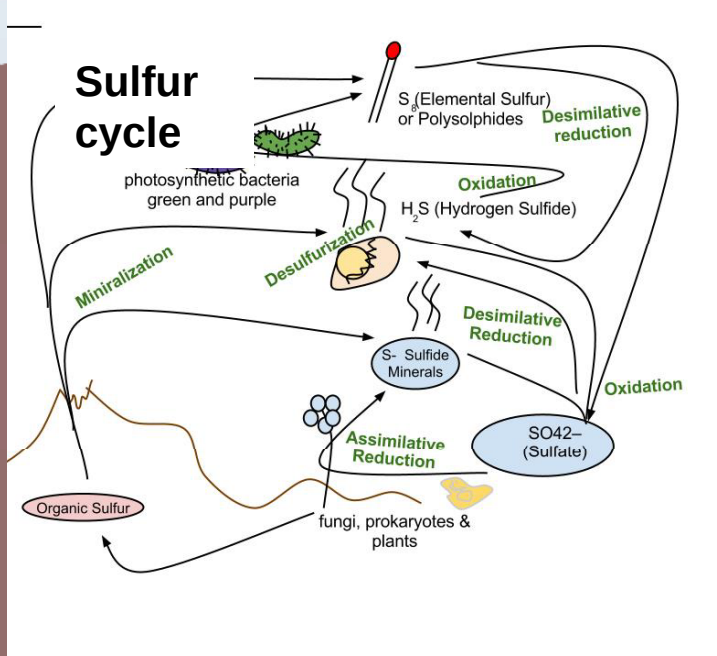


Air and water movement / soil profile

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)

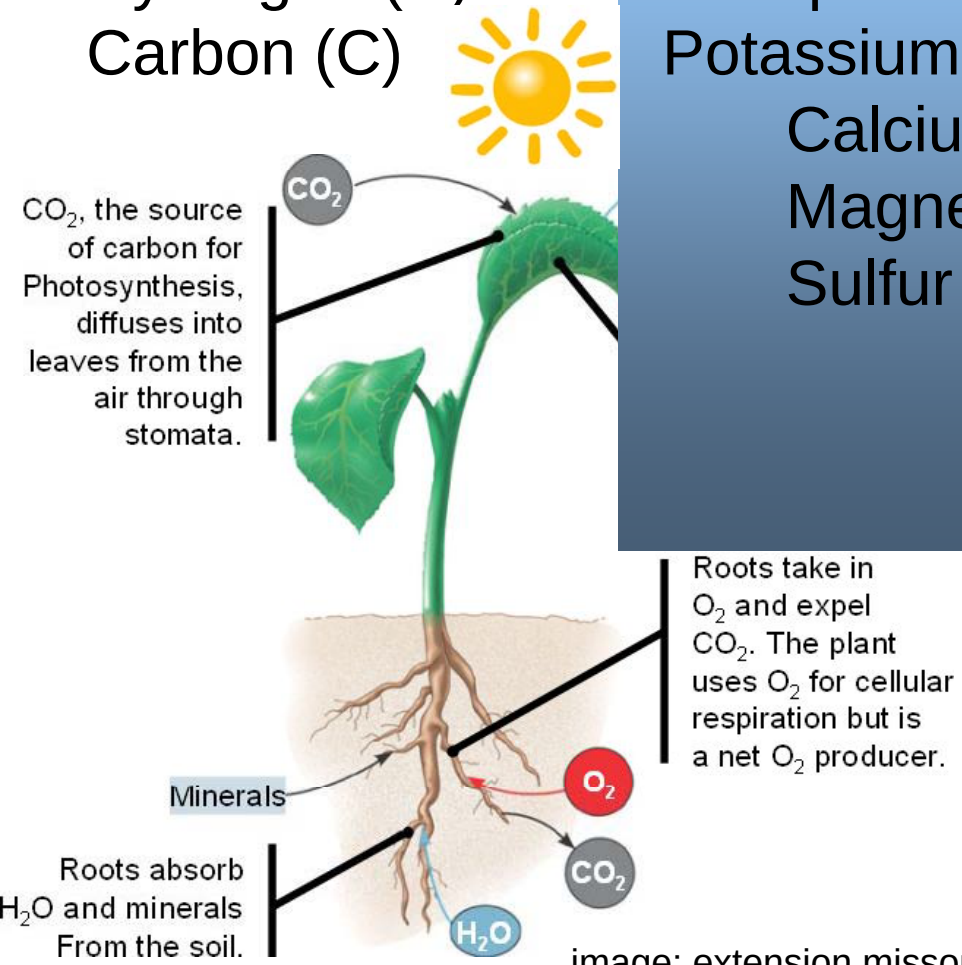
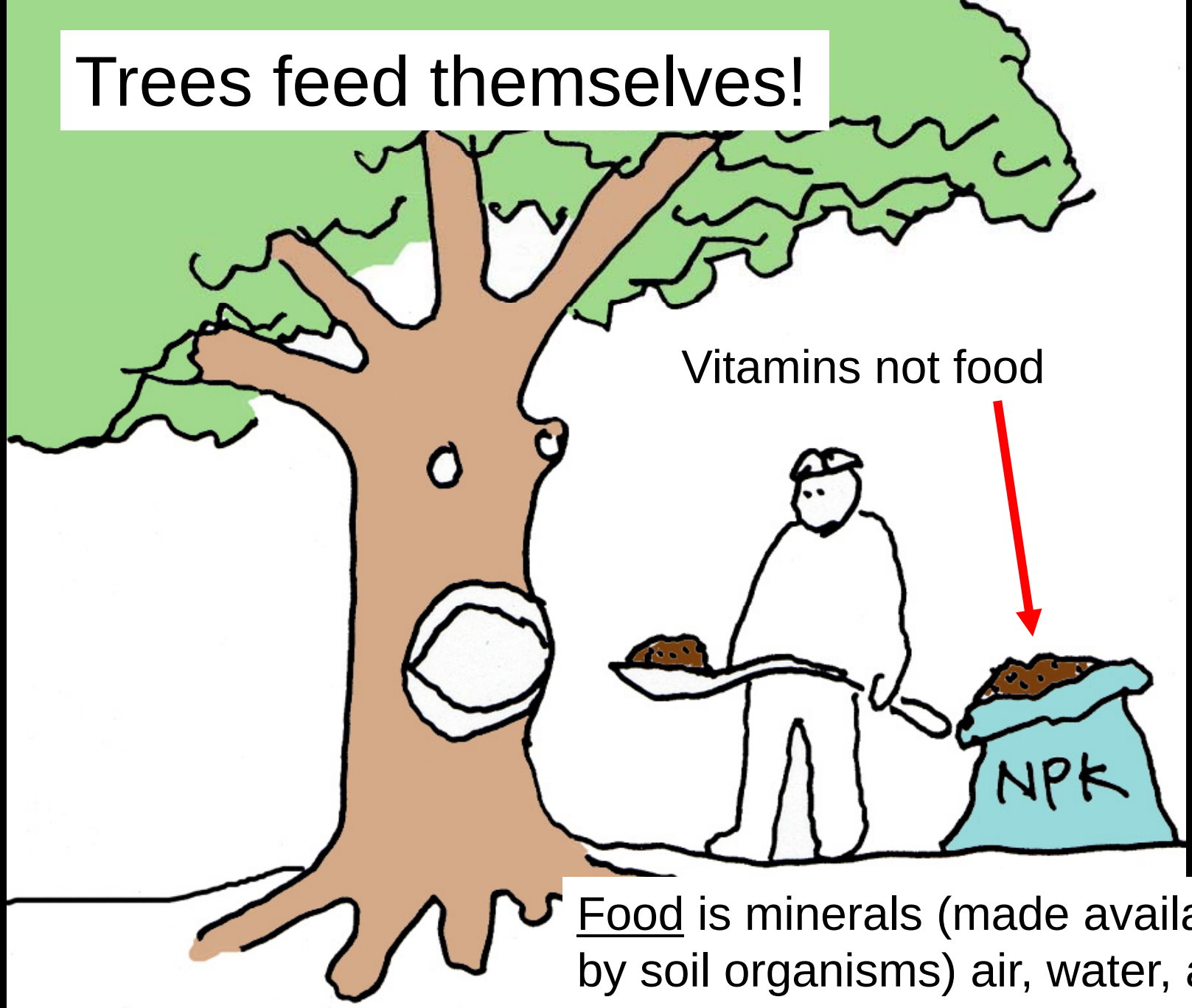


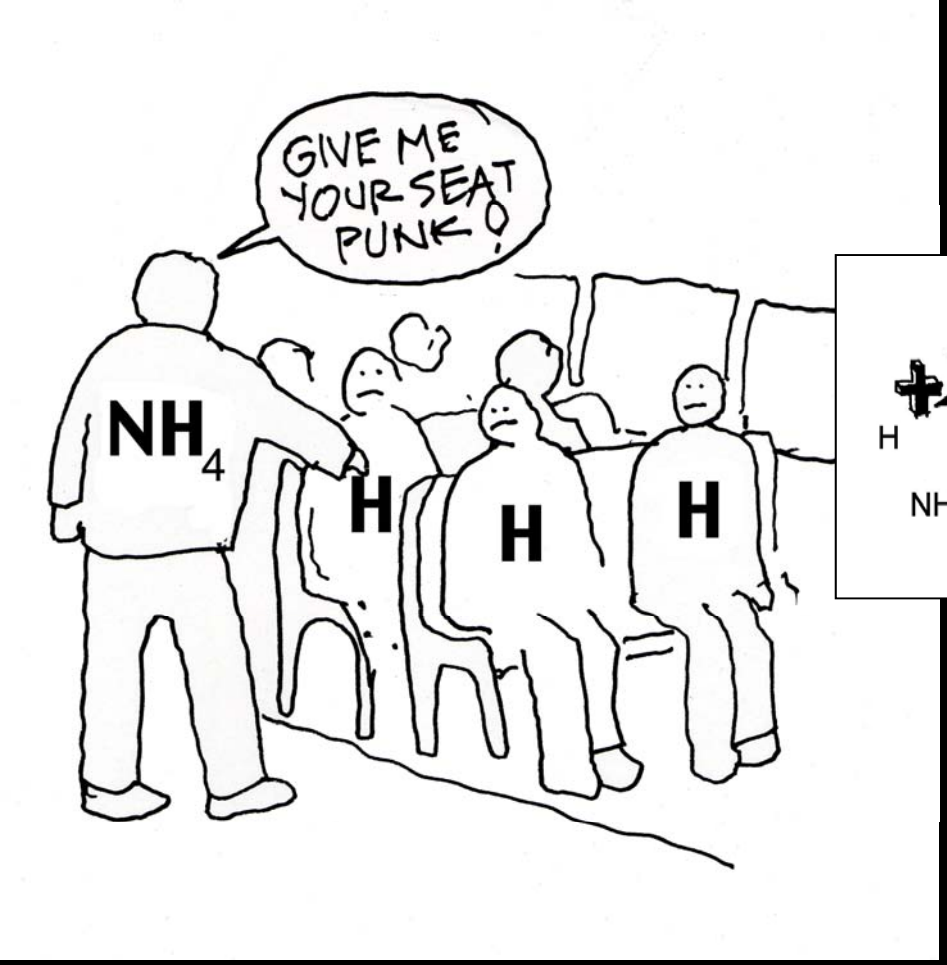
image: extension.missouri.edu

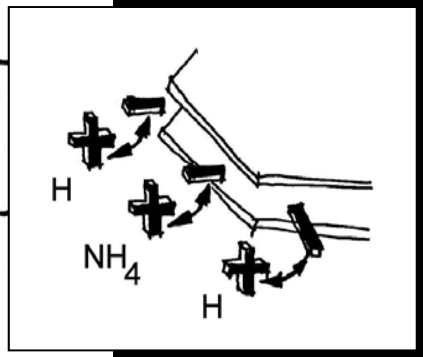
Trees feed themselves!



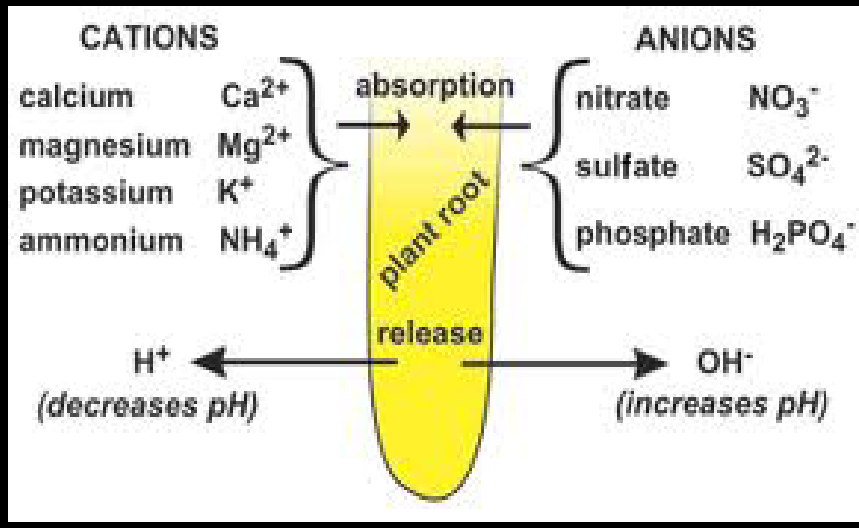
<u>Food</u> is minerals (made available by soil organisms) air, water, and organic matter – leaf fall & mulch

Cation Exchange Capacity (CEC)



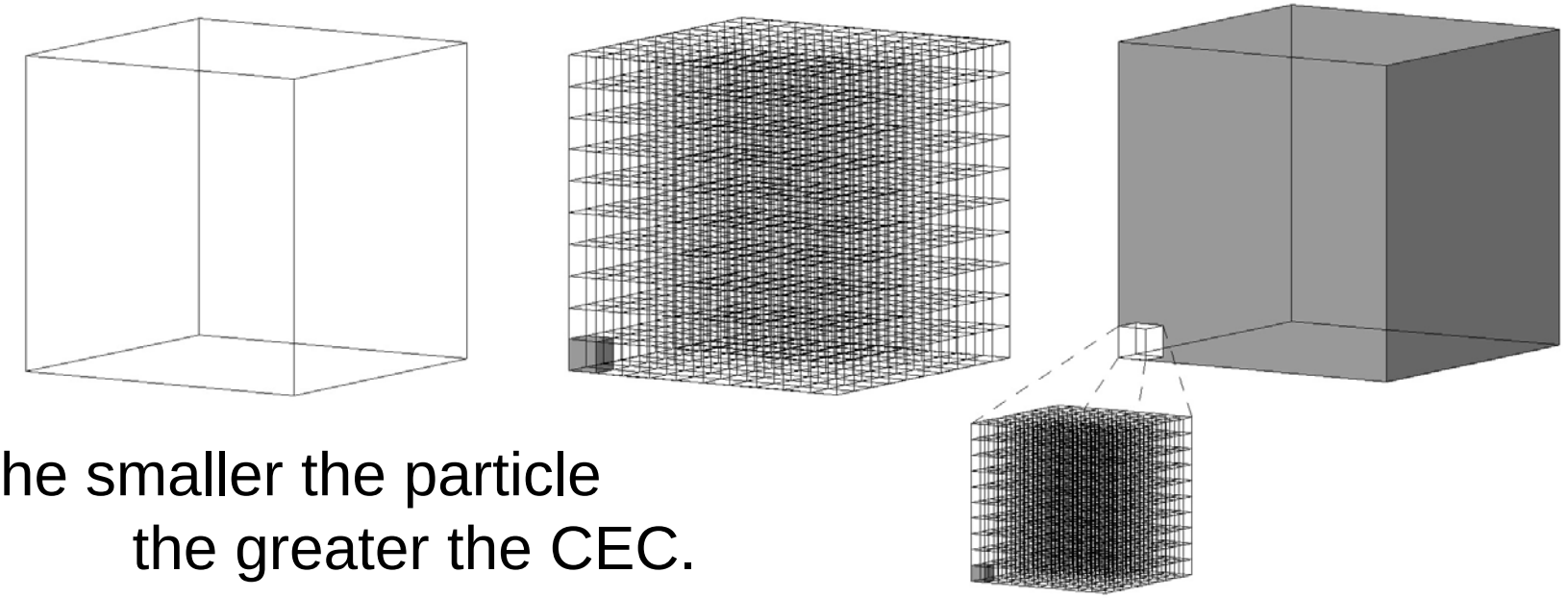


The soil particle is like a bus. The seats are the negative charges. All the seats must always be full with positively charged particles. Hydrogen has a weak charge and Ammonium (NH_4) a stronger charge, so they "exchange" seats if the Ammonium Nitrogen ion wants to sit down.



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

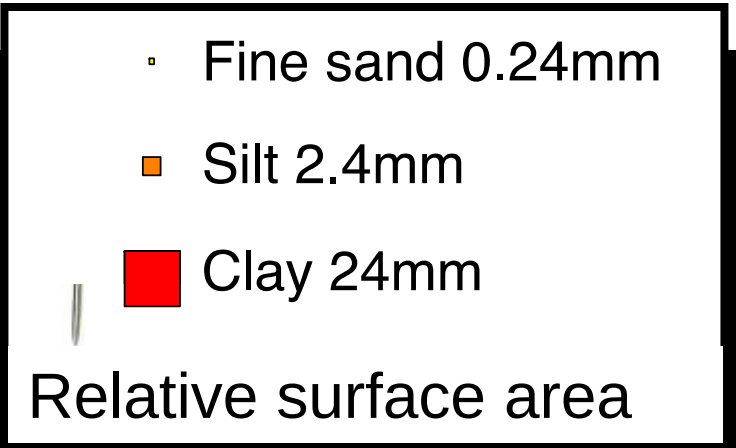
Sand	Silt	Clay
1 Particle Fine **Sand** .2mm 0.24mm^2 Surface Area	1,000 Particles **Silt** .02mm 2.4 mm^2 Surface Area	1,000,000 Particles **Clay** .002 mm 24 mm^2 Surface Area



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!**



Learn different soil odors:
Sweet smell is good respiration = aerobic
Sour smell is no respiration = anaerobic

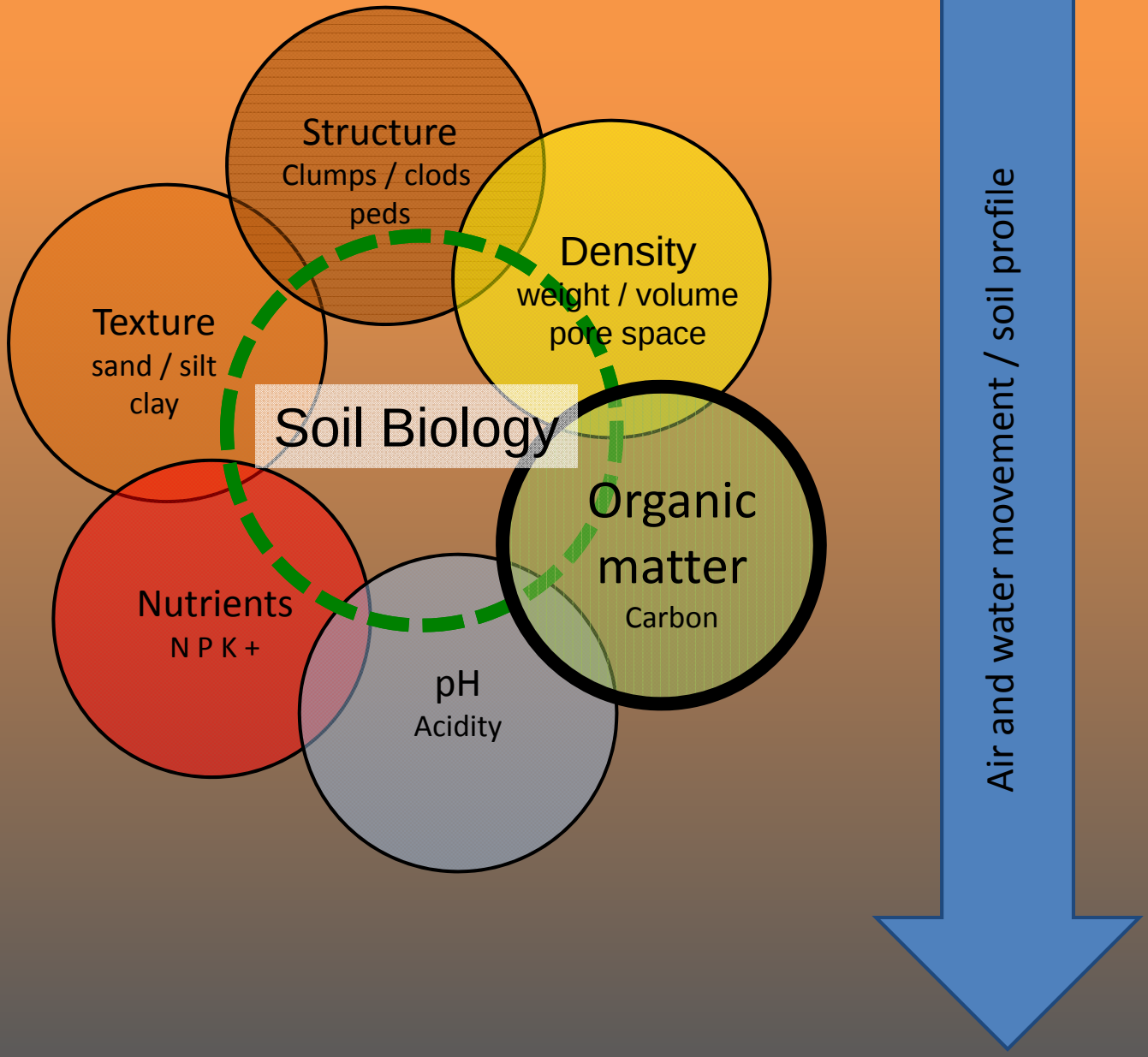
Soil Odor

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

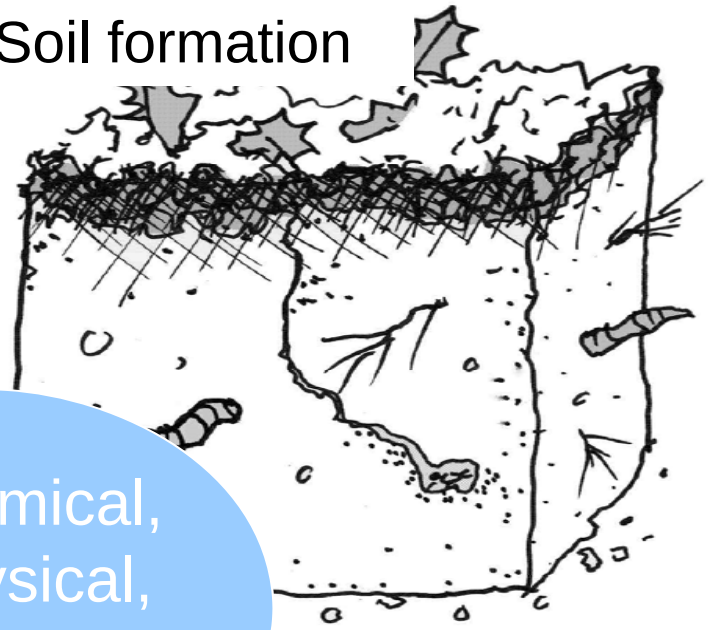
Lower or higher pH decreases availability of different nutrients
Humus (compost) buffers ph towards optimal 6.3 to 6.8

Organic & Biological properties of soil



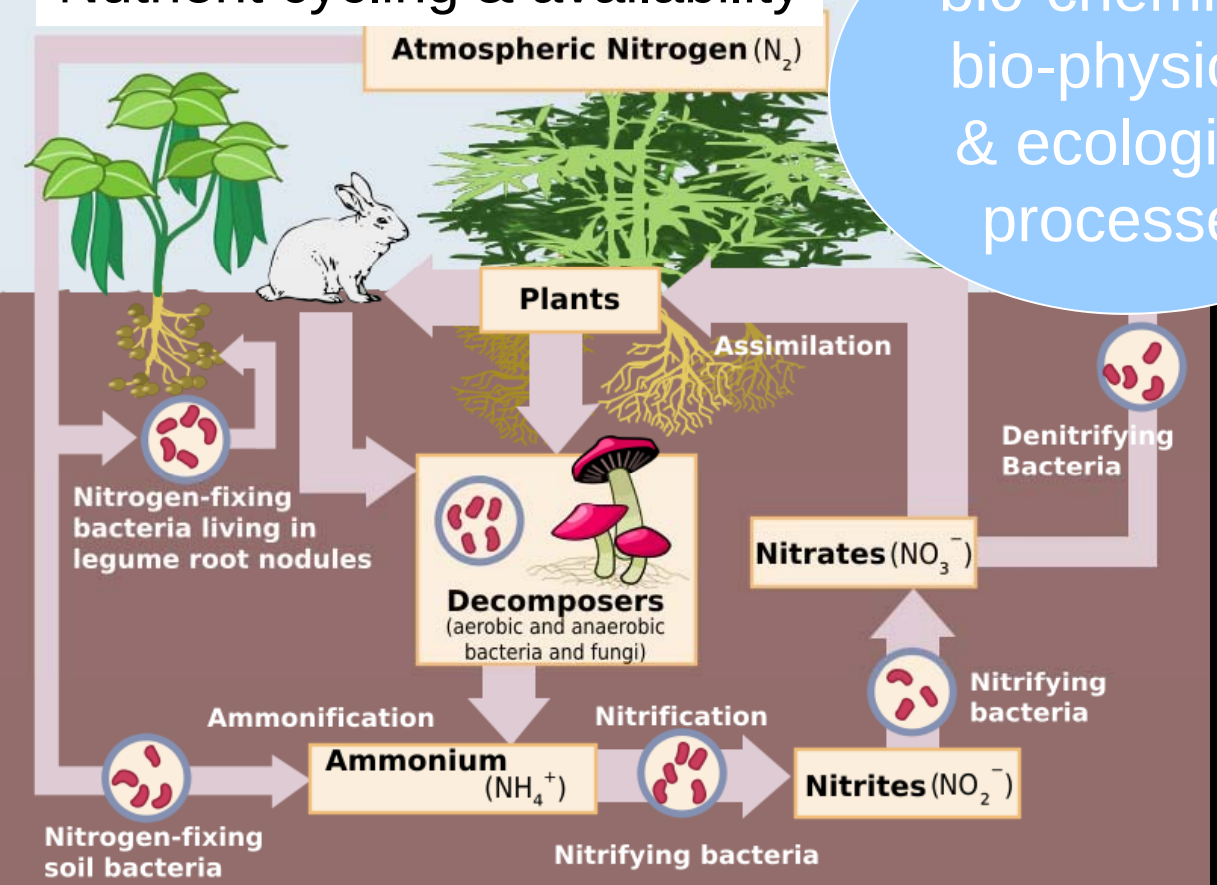
Organic Properties of Soil – *biology in action!*

Soil formation

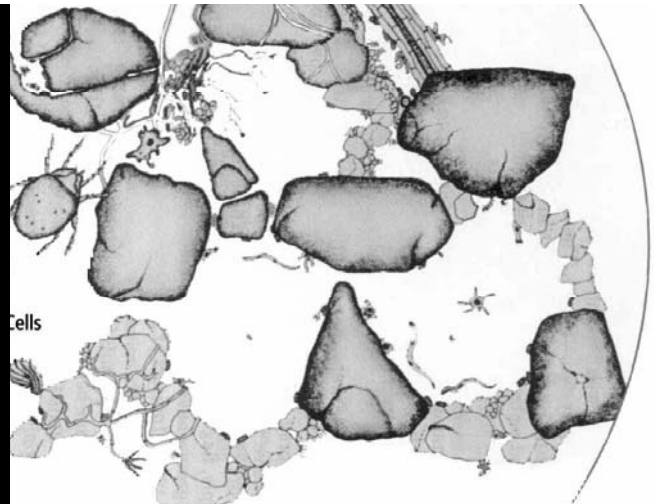


bio-chemical, bio-physical, & ecological processes

Nutrient cycling & availability



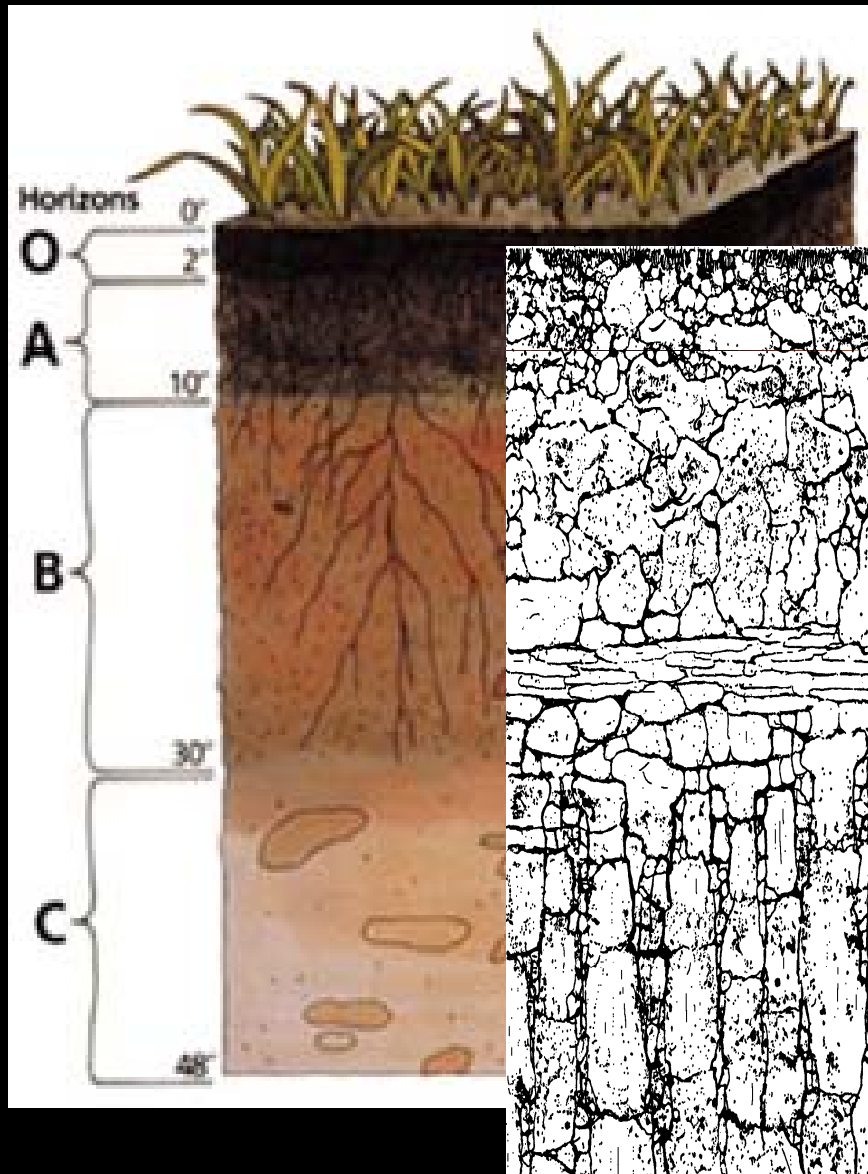
Structure: peds & pores



Soil development processes, from parent “dirt” & rock

Soil horizons & their evolution

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

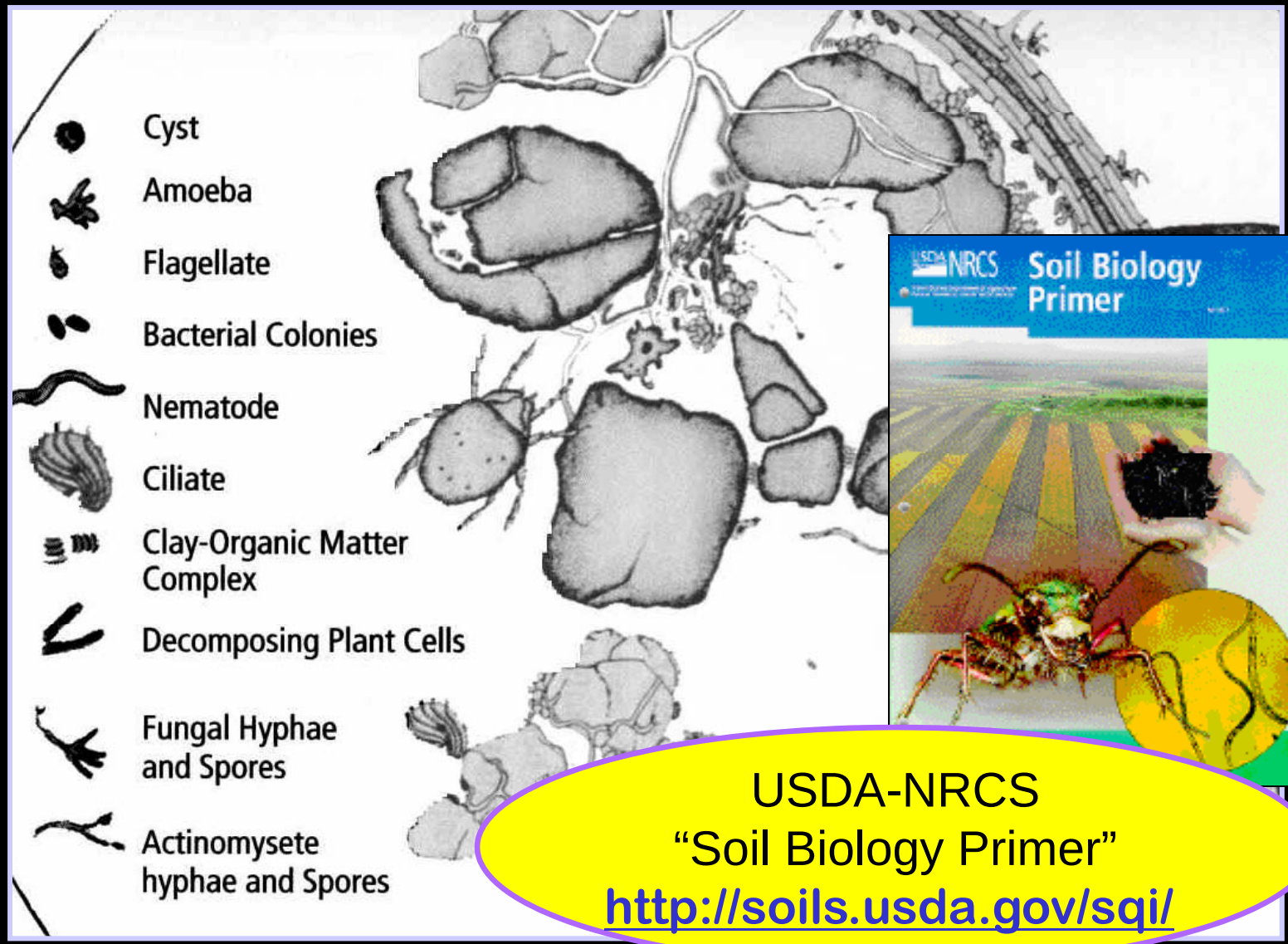


USDA - NRCS

http://soils.usda.gov

Understanding Soil Biology
Soil life provides essential functions

Soil is alive!

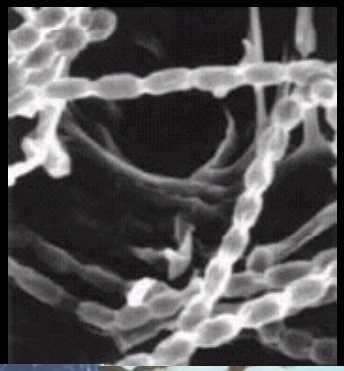


USDA-NRCS
"Soil Biology Primer"
http://soils.usda.gov/sqi/

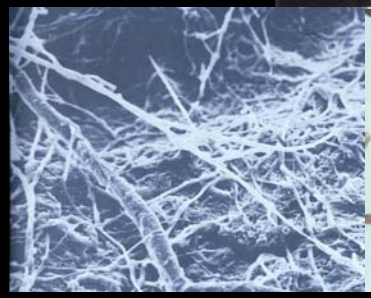
S. Rose & E.T. Elliott

Common organisms in the soil foodweb

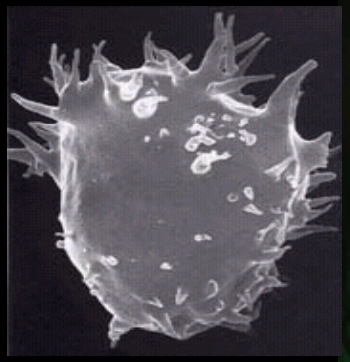
Bacteria



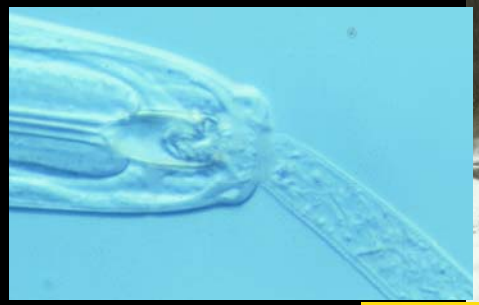
Fungi

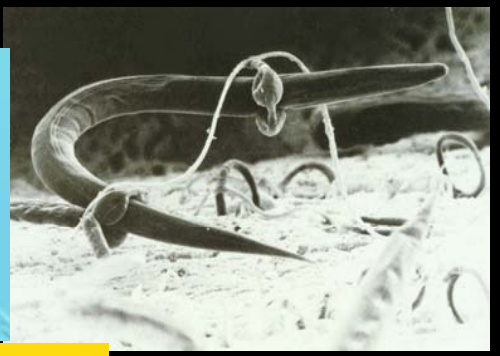


Protozoa



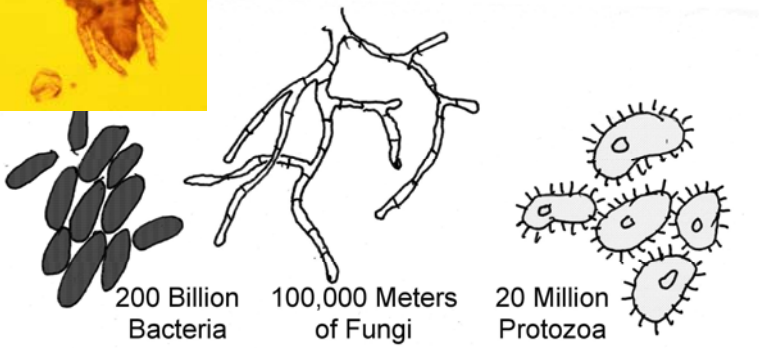
Nematodes

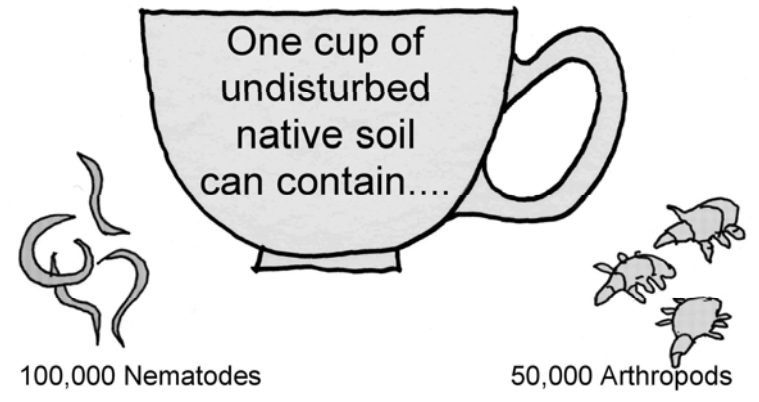




Arthropods

Earthworms



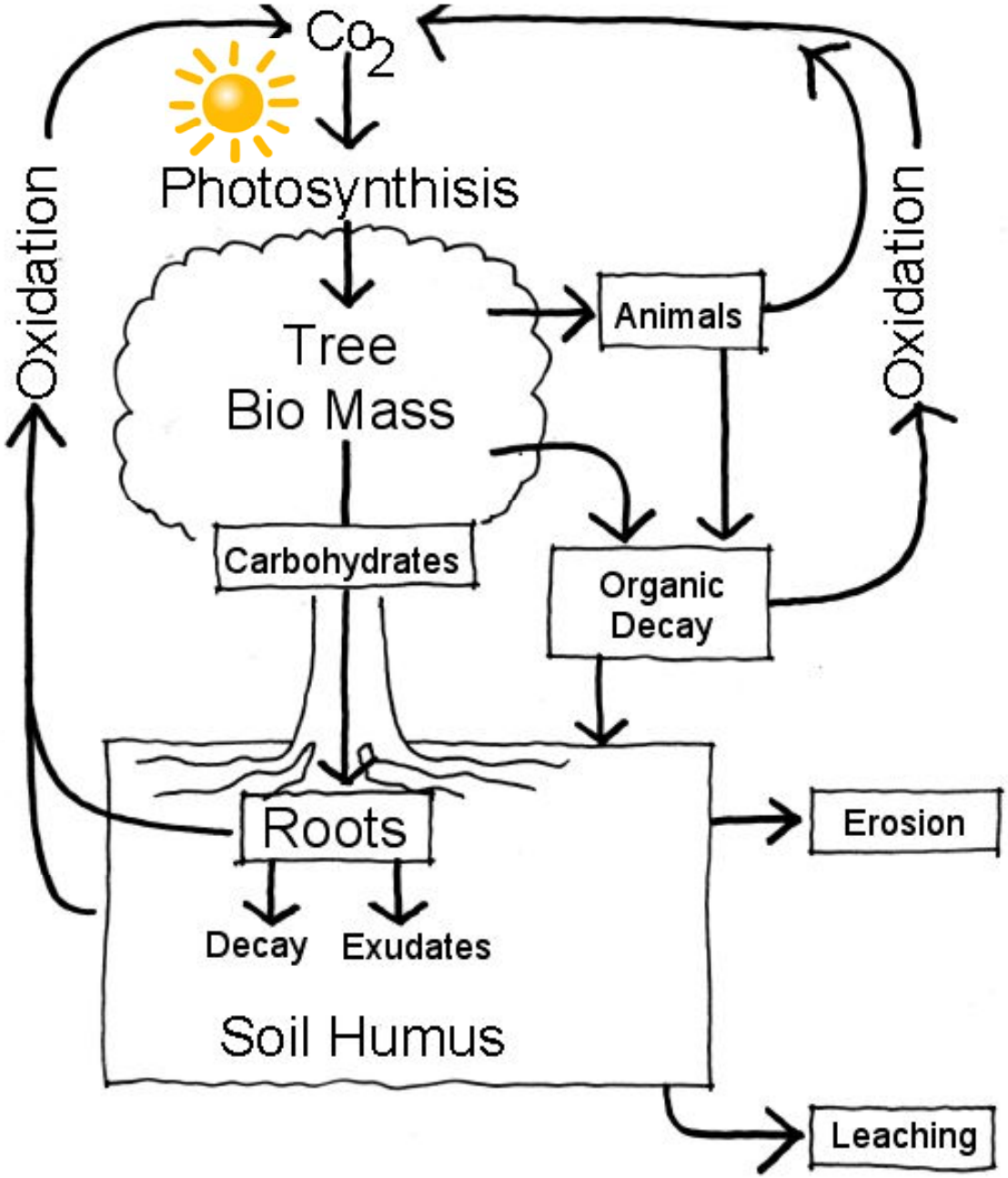


What Fuels the Soil Foodweb?

Plant photosynthesis:

Sunlight → living and dead organic matter

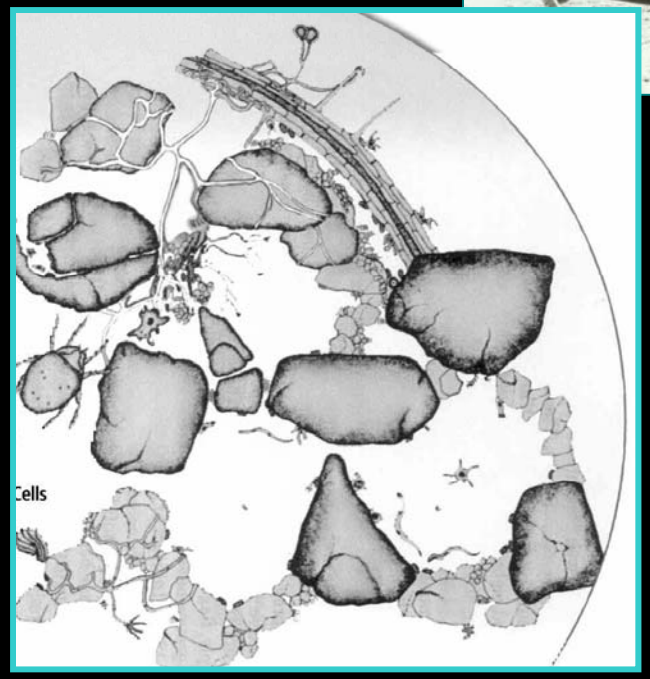
Plants exude 20-30% of their photosynthetic energy as carbohydrates released in the root zone to feed beneficial soil organisms (bacteria & fungi).



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



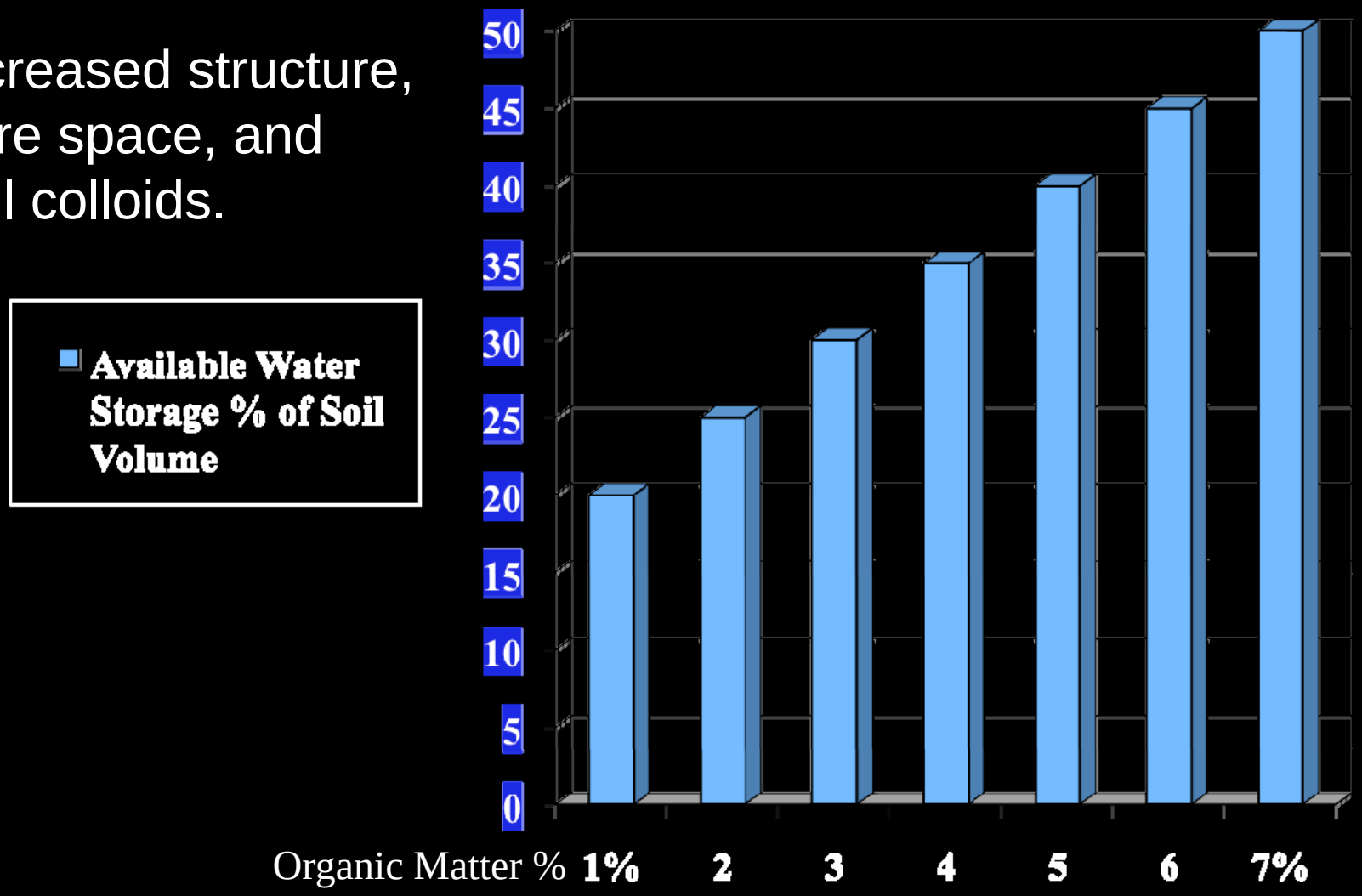
Compost kickstarts the soil ecosystem!
(Provides food and home for organisms)

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.

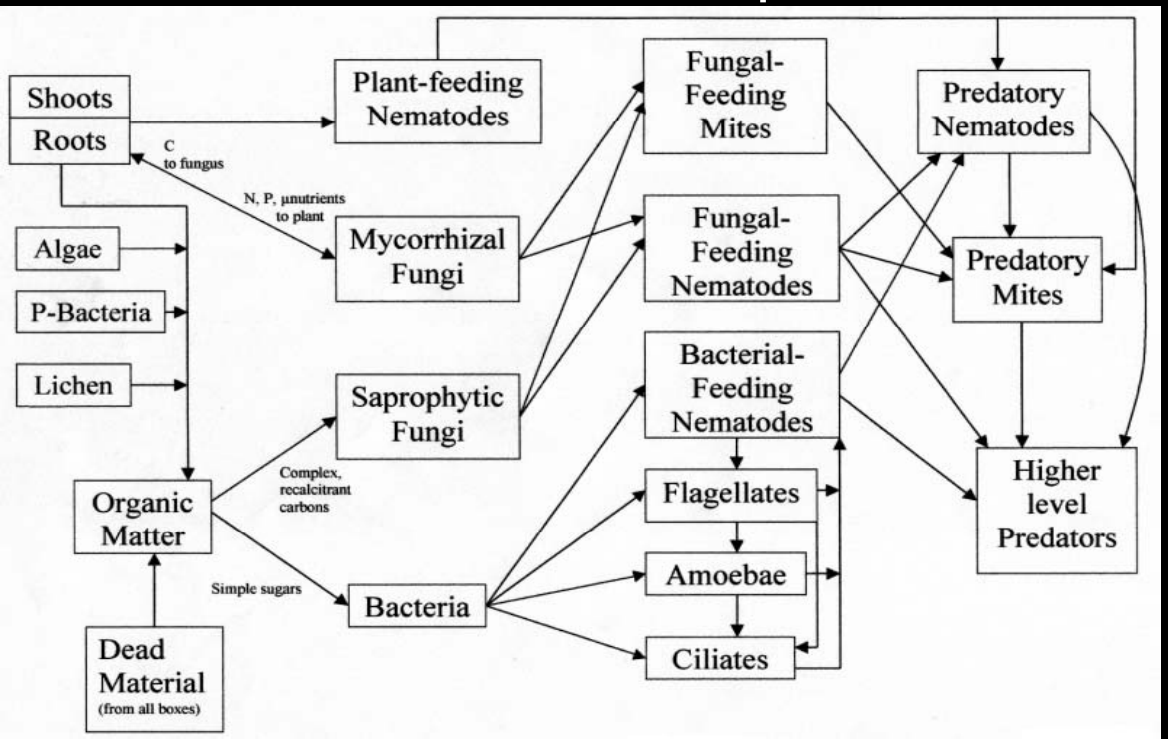
How does soil life and increasing organic matter increase plant-available soil water storage?

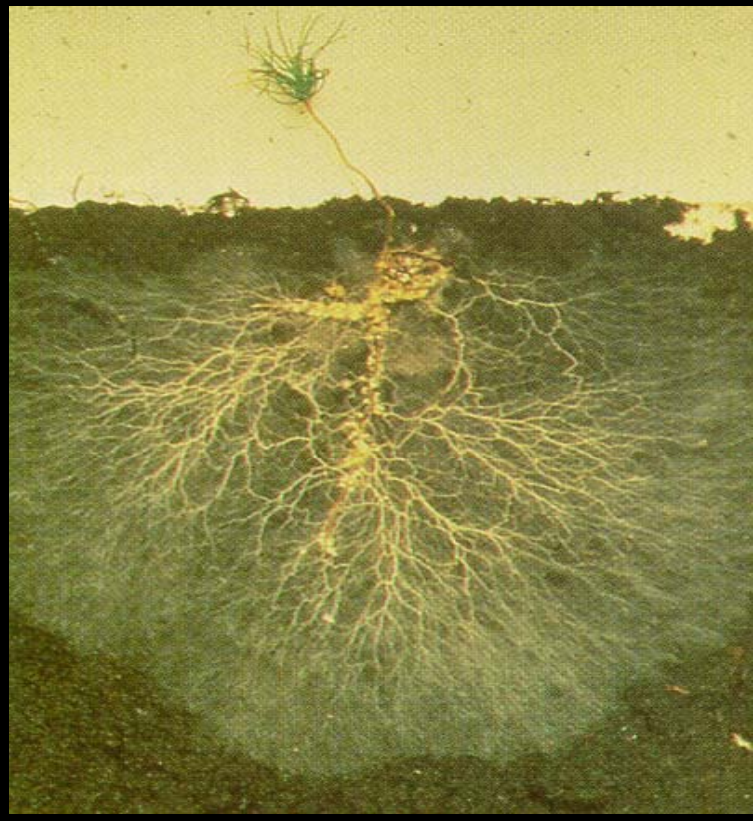
Increased structure, pore space, and soil colloids.



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



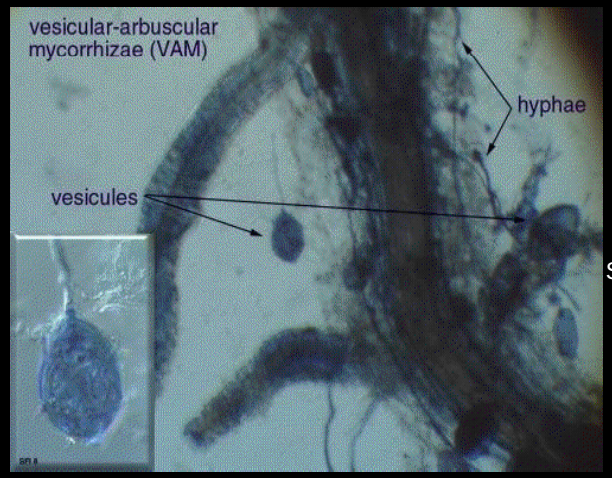


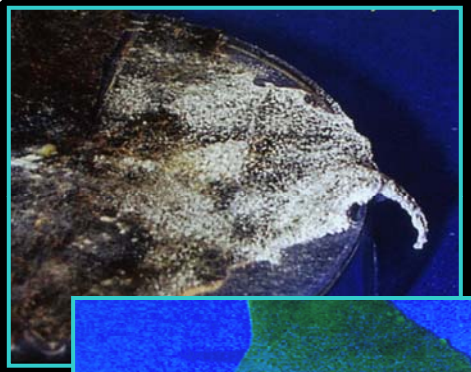
Dr. Michael P. Amaranthus, Mycorrhizal Applications Inc.

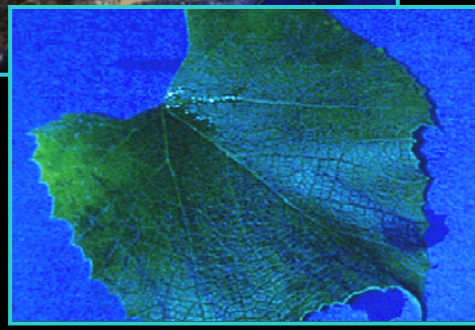
How does soil life provide plant disease protection?

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

- Bacteria cover leaf surfaces, block infection
- Ecto- and endo-mycorrhizae prevent root infection
- Many organisms prey on the few disease-causing organisms







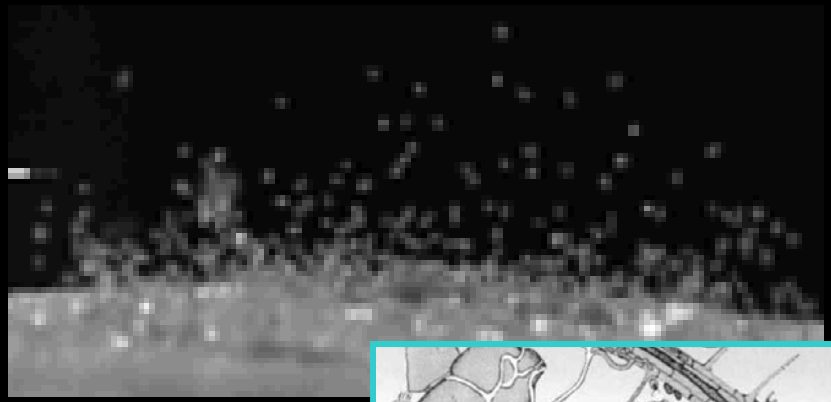
Soil Foodweb Inc.

SSSA

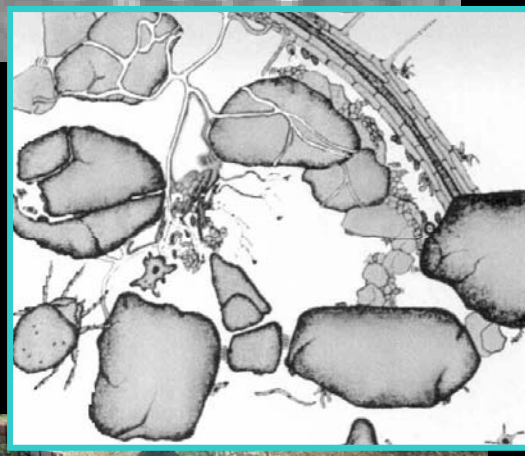
How does soil life filter out urban pollutants?

- 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 control erosion?



- Creates pore spaces, increases infiltration

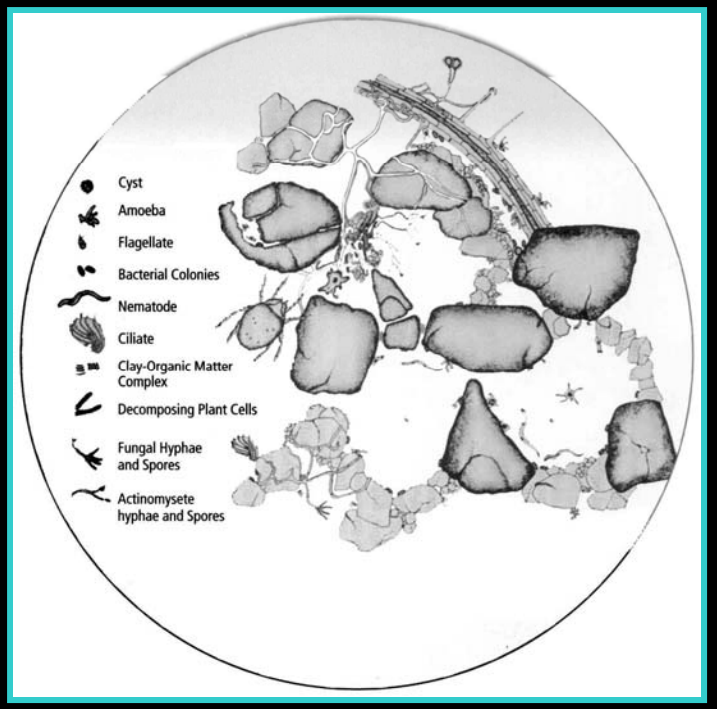


- <u>Sticks soil particles & aggregates together</u> with bacterial slime, fungal hyphae, & root hairs (bigger aggregates are harder to move)
  → “aggregate stability”

- Promotes rapid plant growth & deep root development

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 feed soil life

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

Clearing up the confusion about **"% organic**"

"% Soil Organic Matter Content" in lab soil tests is by loss-on-ignition method

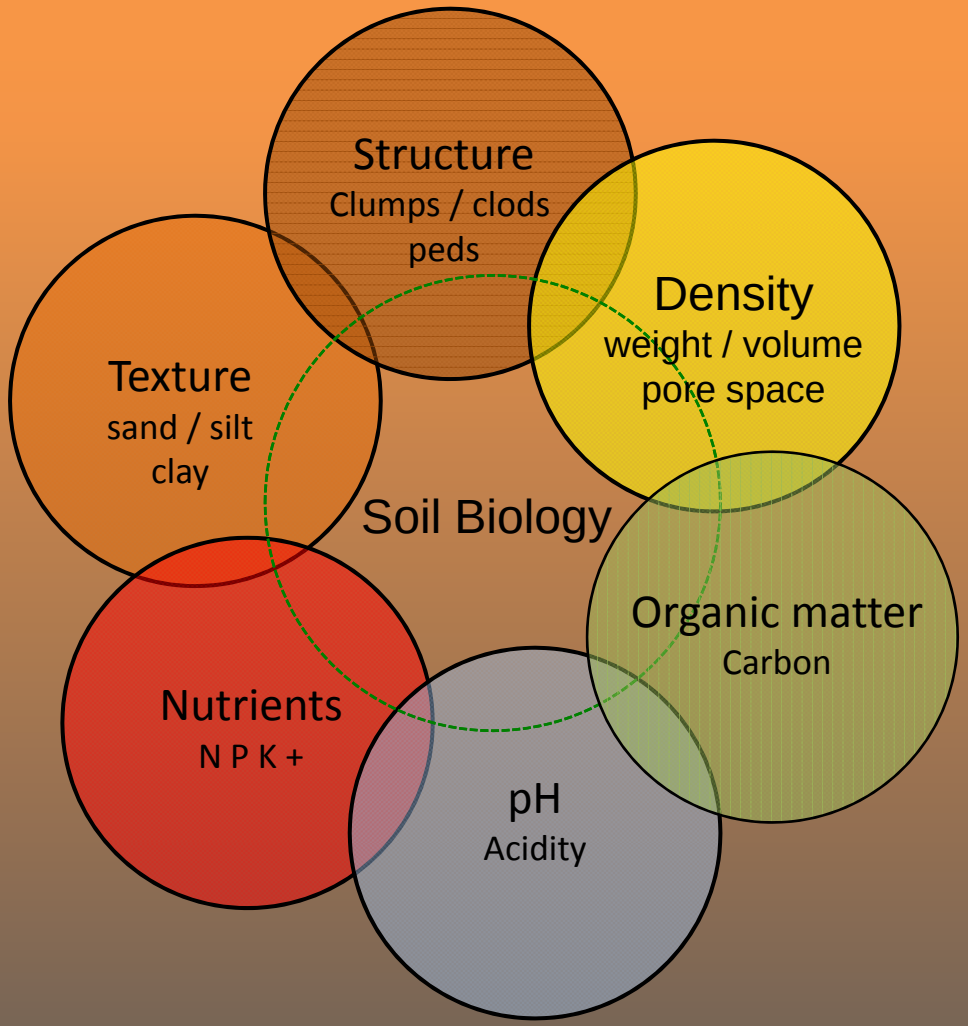
- Most composts/plant materials are 40-70% organic content by this method.

?

Recommended soil amendment rates
(for low-organic soils or soil/compost topsoil mixes):

- 3% Soil Organic Matter (by lab test) for Tree soils
  = 10-15% compost amendment into soil by volume
- 5-8% Soil Organic Matter (by lab test) for Turf/Landscape
  =15-25% compost amendment by volume
- 10% Soil Organic Matter (by lab test) for Stormwater bioretention soil mixes
  = 30-40% compost amendment by volume

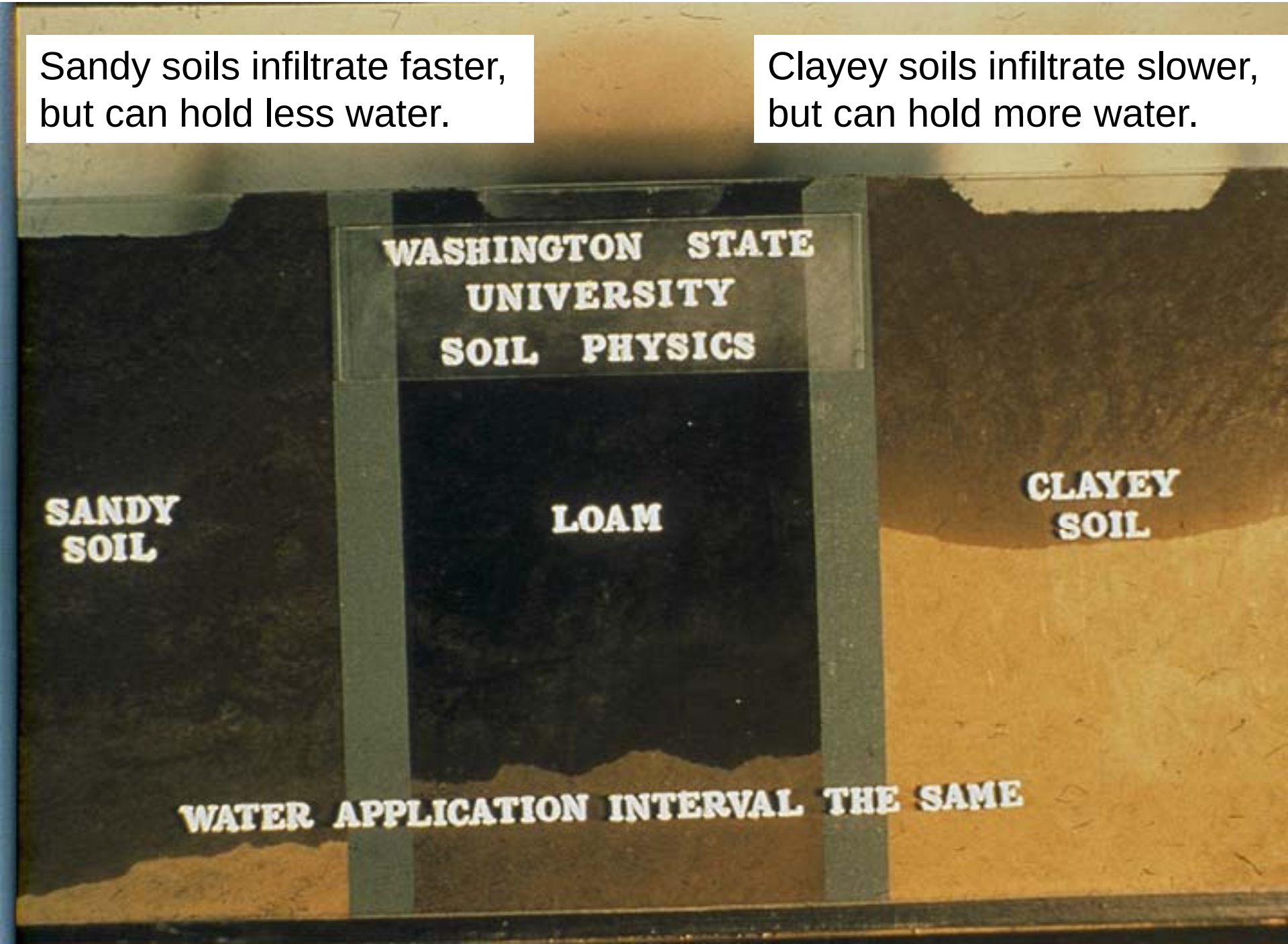
Air and water movement in soil

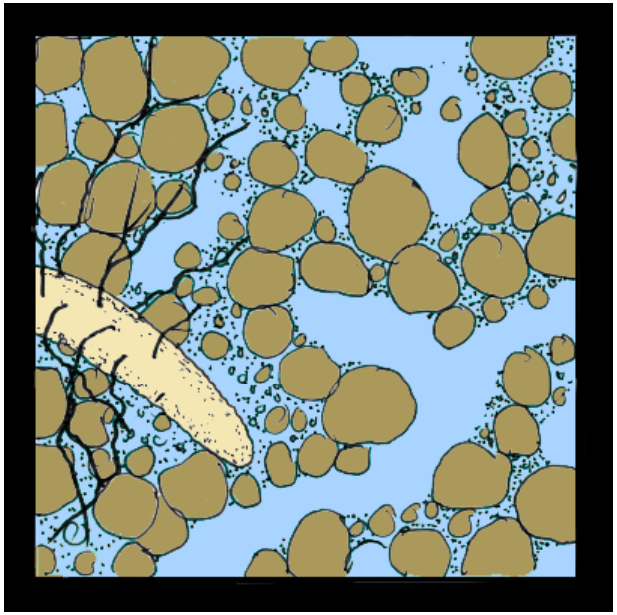


Air and water movement / soil profile

Sandy soils infiltrate faster, but can hold less water.

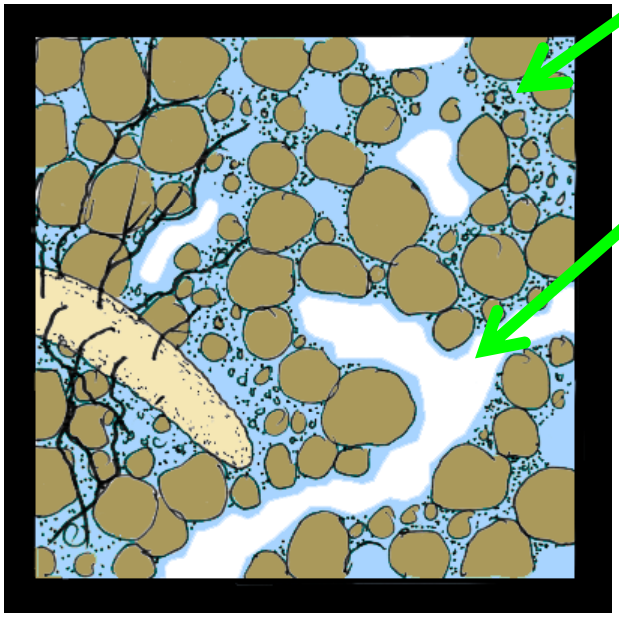
Clayey soils infiltrate slower, but can hold more water.





Saturation Point

all pores full

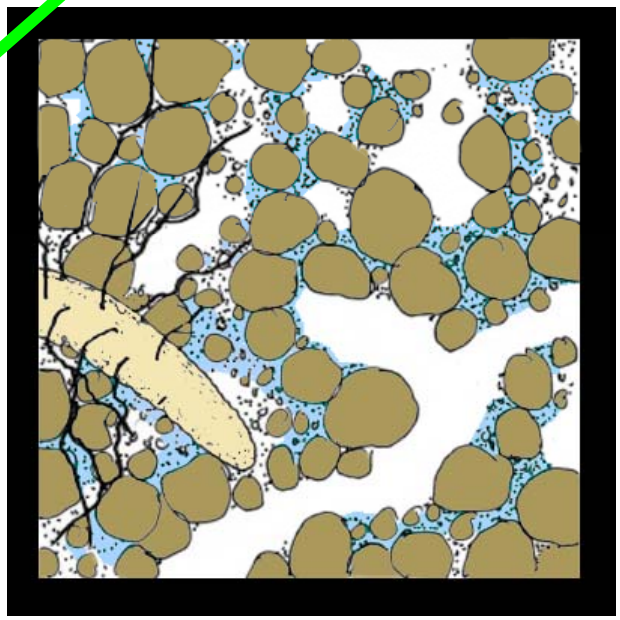


Micro-pores

Macro-pores

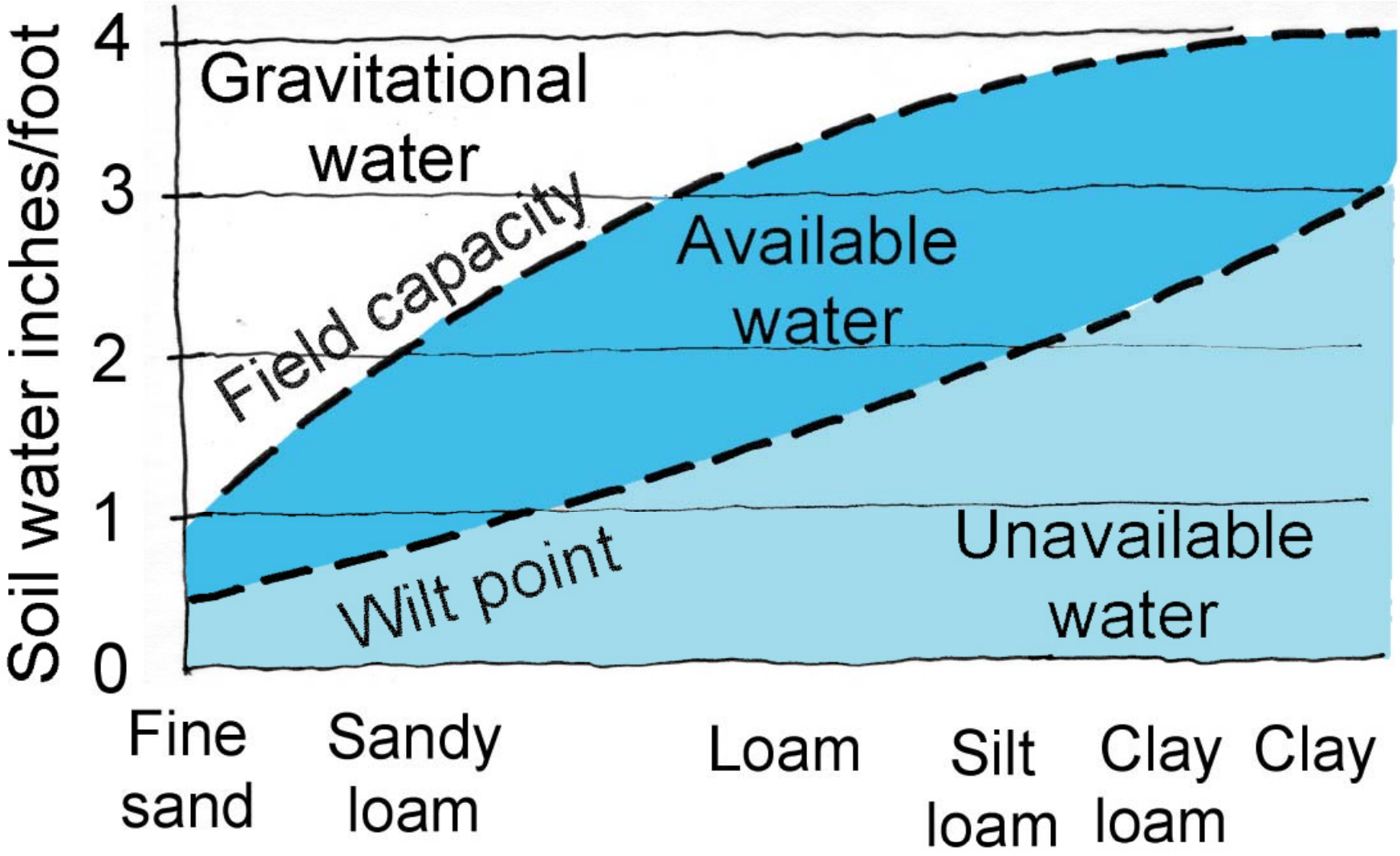
Field Capacity

gravitational water has drained out

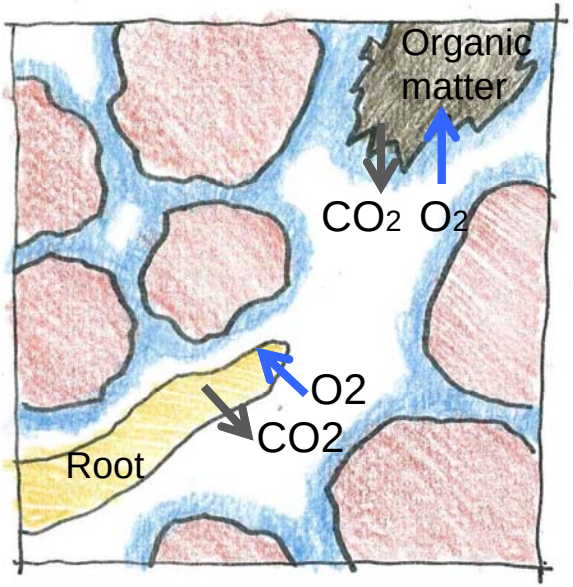


Wilt Point

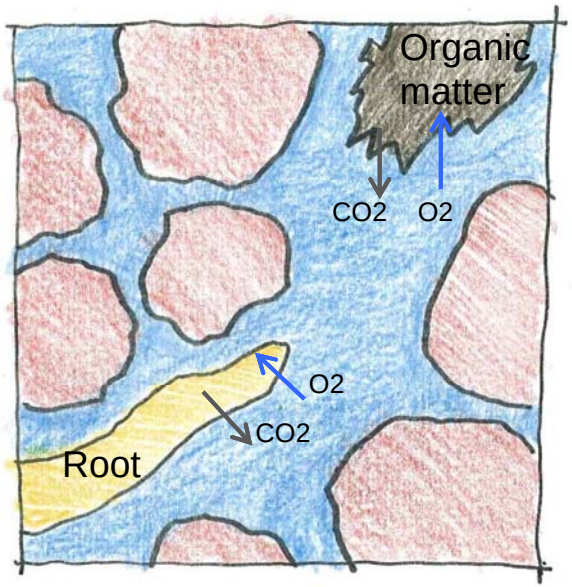
remaining water held in micro-pores too tightly for plants to suck it out


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

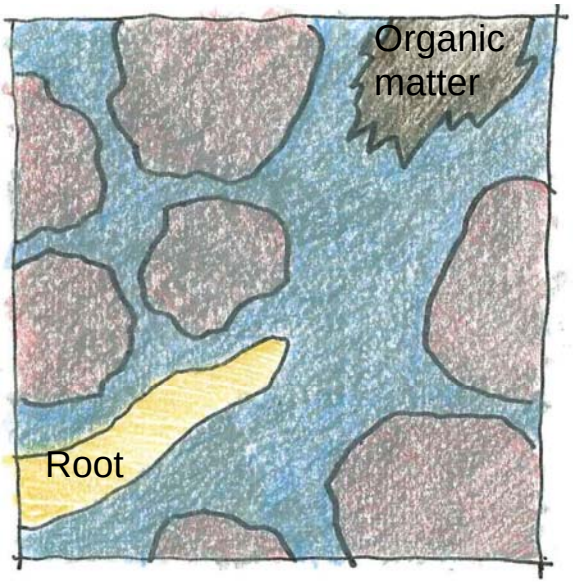
Plants and decaying organic matter in soil must respire (bring in oxygen expire carbon)



Aerobic Soil
Good respiration

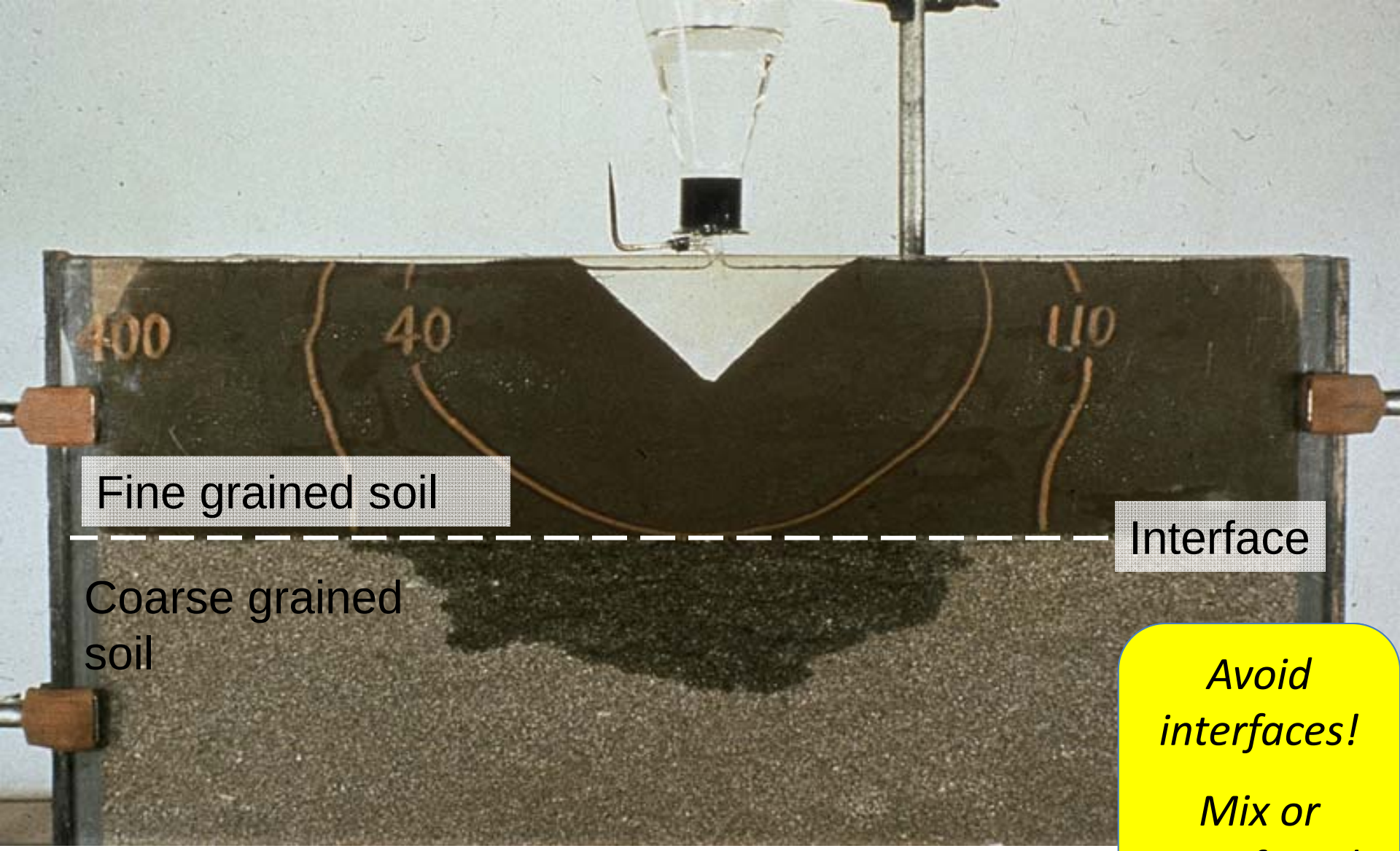


Saturated Soil
Slow respiration



Anaerobic Soil
No respiration

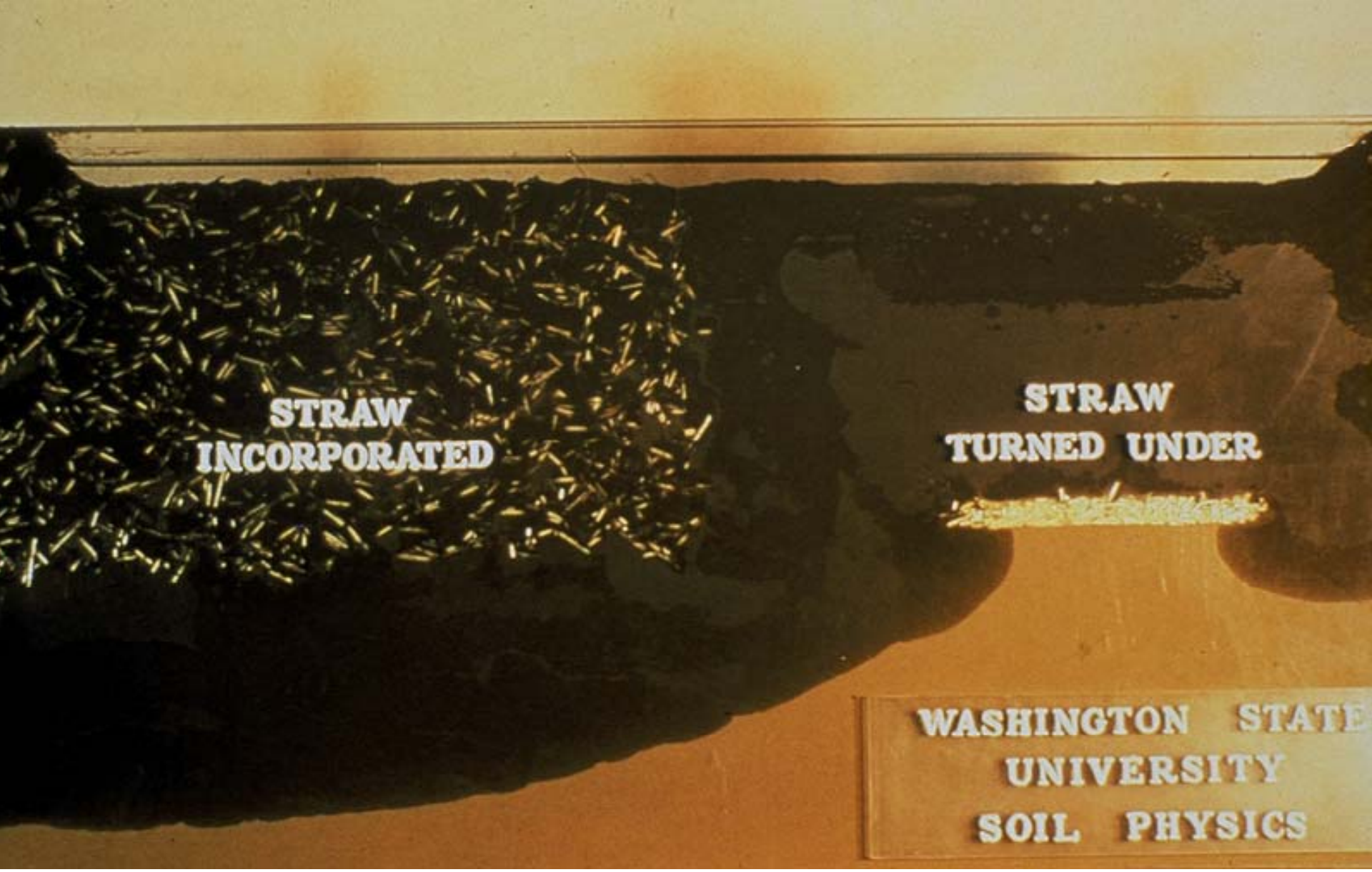
Plants will die more quickly with too much water than too little !!!!!



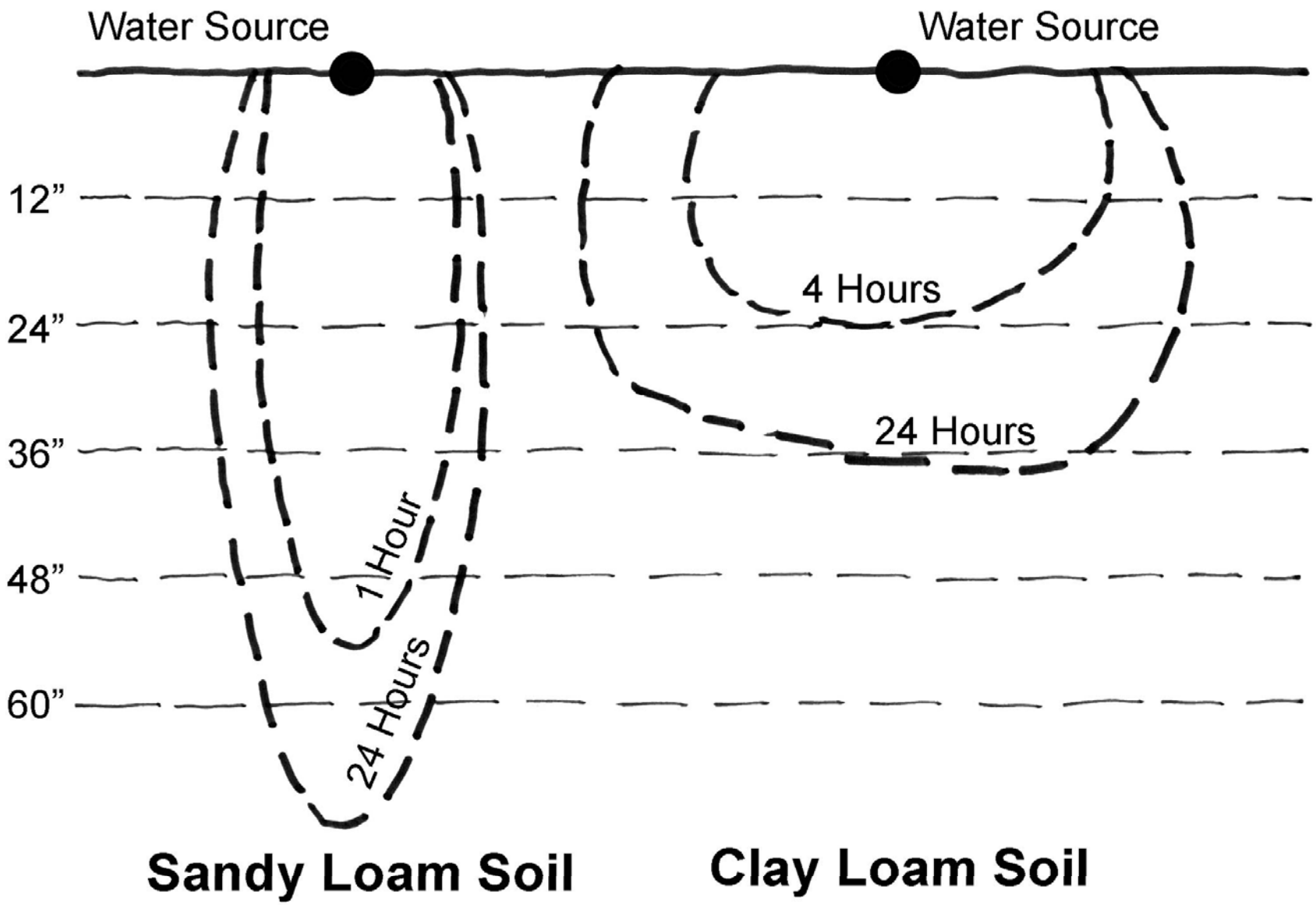
Avoid interfaces!

Mix or scarify soil layers

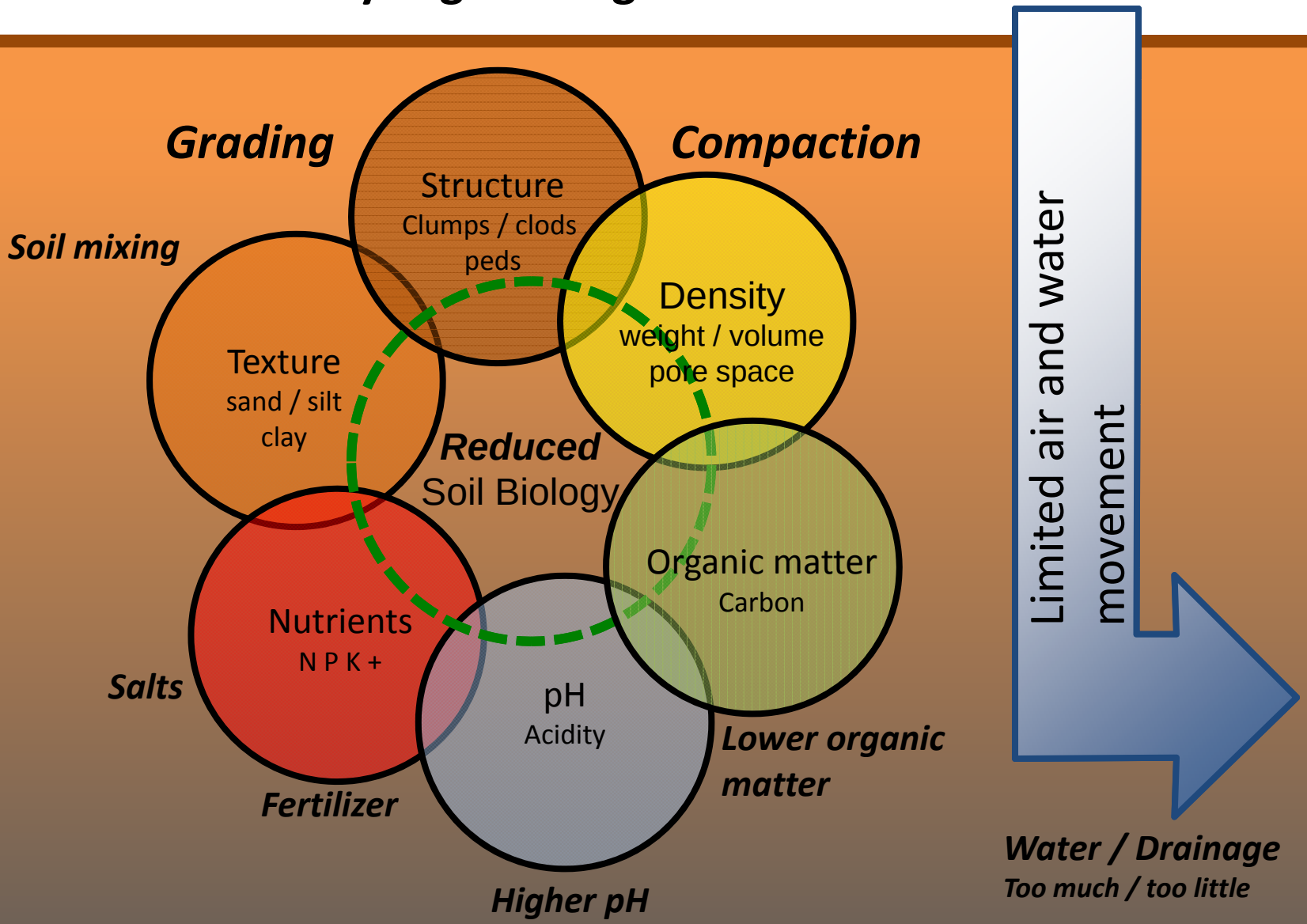
Soil interface slowing the flow of water
Upper layer must become saturated before water moves into lower layer

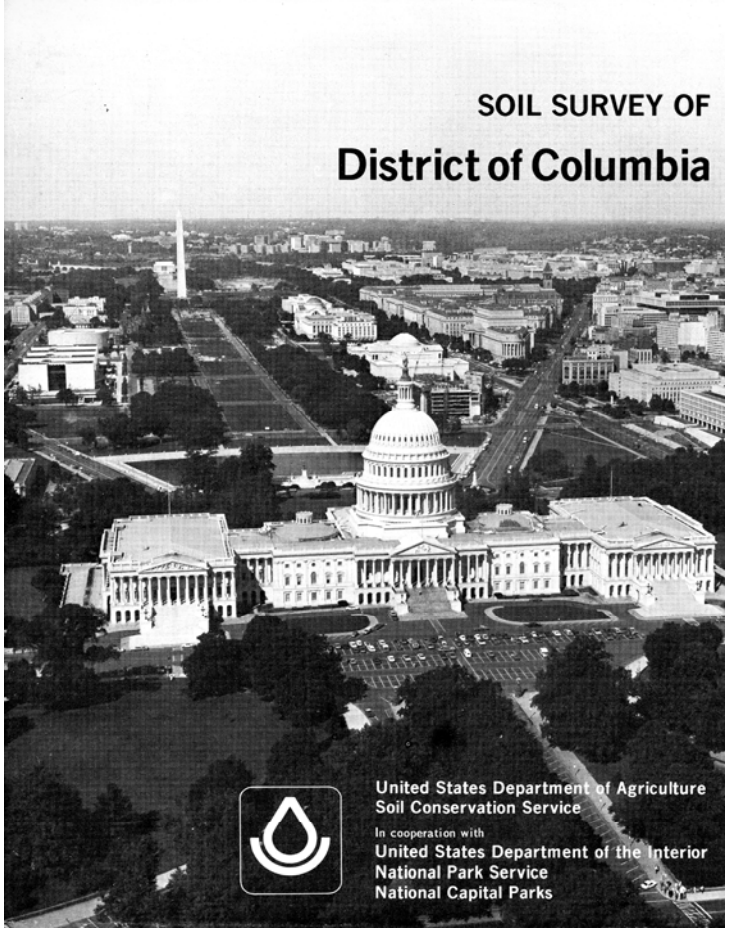


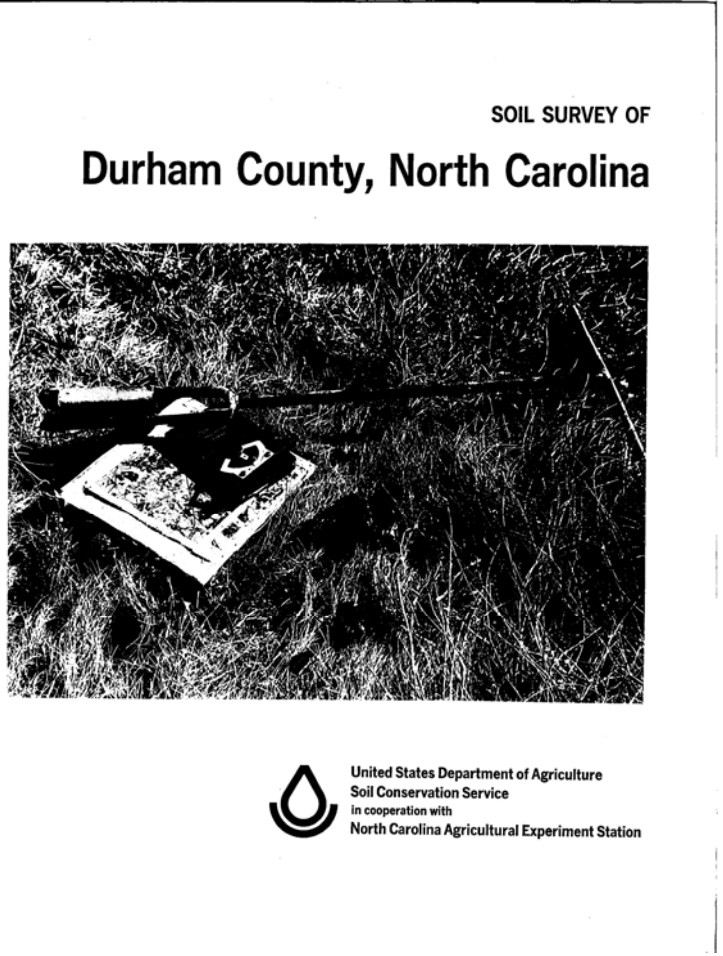
Organic material layers can also limit water movement – *mix organics into soil.*


Water Source
Water Source
12”
24”
36”
48”
60”
4 Hours
24 Hours
1 Hour
24 Hours
Sandy Loam Soil
Clay Loam Soil

Analyzing Existing Site Soil







Soil Survey

1. The existing survey description
2. Changes since development
3. 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

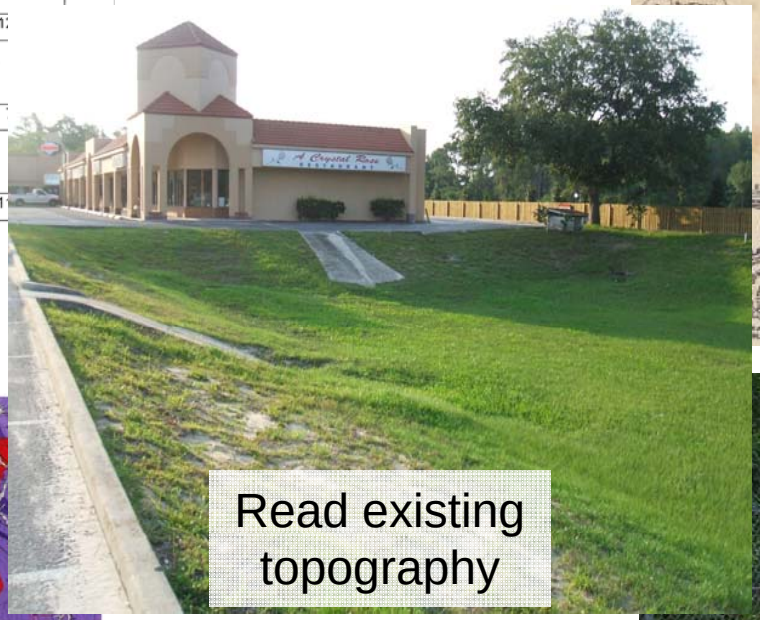
	Sort of Bad	Good	Real bad
Drainage	Excessive Dry	Moist but well drained	Excessively Wet
Compaction	Very Loose	Consolidated or Aggregated	Very Compacted
Organic Content	Greater than 10% or less than 2%	2-3%	0.5 - 0%
Texture	High sand	Loam	High Clay or Silt
Fertility Indicators	high or Low	Just Right	Very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

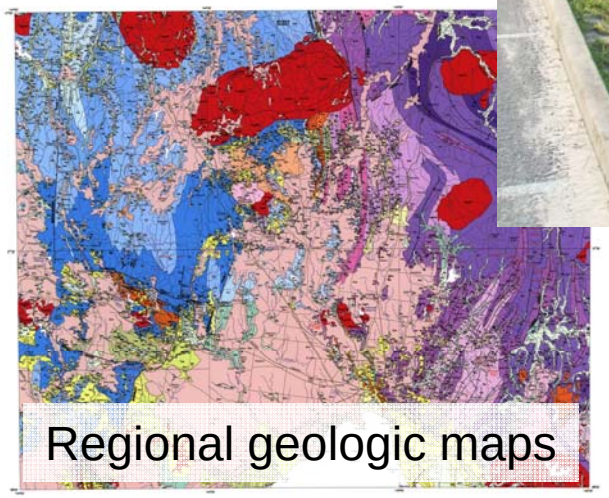
Boring No.: B-15 | Total Depth 25.0' | Surface Elev: 673 (approx.)
Type of Boring: HSA | Equipm't: | Started: 2/23/06 | Completed: 2/23/06

Approx. Elevation**	Depth**		Sample Blows*	Sample Depth (Feet)
672.2	0.8			1.0
670.0	3.0	Brown, et. indy	2-2-2	2.5
		SILT (ML) - moist to wet.		3.5
667.0	6.0		5-7-9	5.0
		Loose, Tan and Gray, Clayey Silty Fine SAND (SM) - moist to wet.	3-4-6	6.0
665.0	8.0			7.5
		Stiff, Gray and Tan, Sandy Lean CLAY (CL) with trace rootlets - moist to wet.	4-4-5	8.5
				10.0
661.0	12.0	Dense, Tan, Silty Fine SAND (SM) - moist to wet.		
656.0	17.0	Very Stiff, Tan and Gray, Sandy SILT (ML) - moist.		
651.0	22.0	Dense, Brown, Silty SAND (SM) - moist to wet.		
648.0	25.0	Boring Terminated at 25 feet Groundwater: 0 Hour - 14.5 feet 1 Hour - 4.5 feet Stabilized - 2 feet		



Read existing topography

Old maps and photos



Regional geologic maps

Interviews

Plants as indicators of soil differences and problems

Compare urban tree leaf growth with those from nearby native soils.


Stressed tree
Poor soil
Healthy tree
Good soil

Early Fall Color
indicating soil stress

WSDOT

I-5 Marvin Rd. Interchange

Which site is selling the next job?

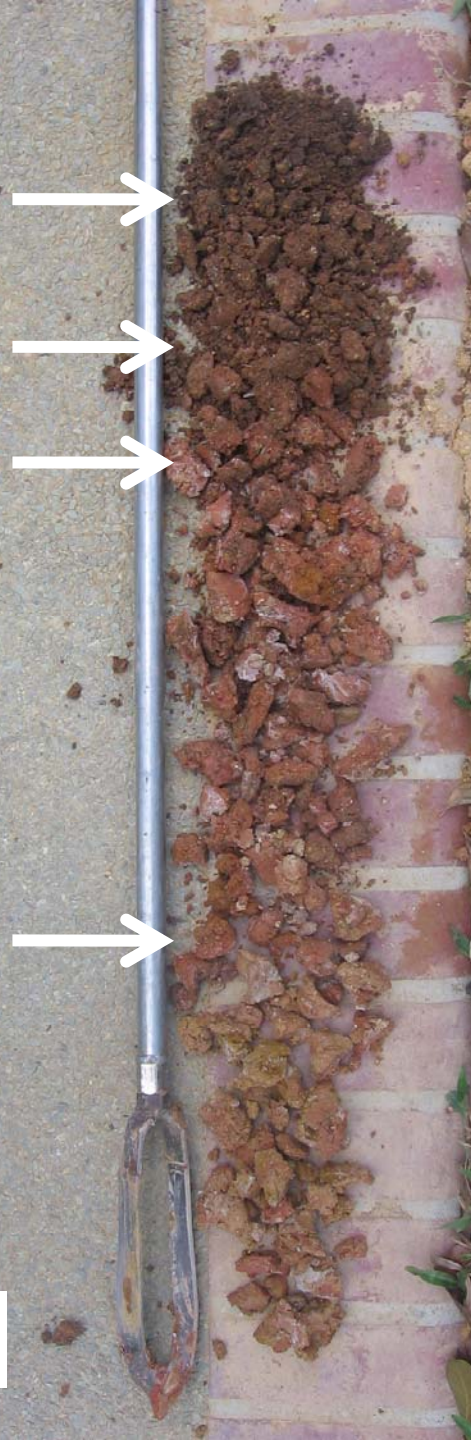
Which needs more water, fertilizer, weed control?

Compost

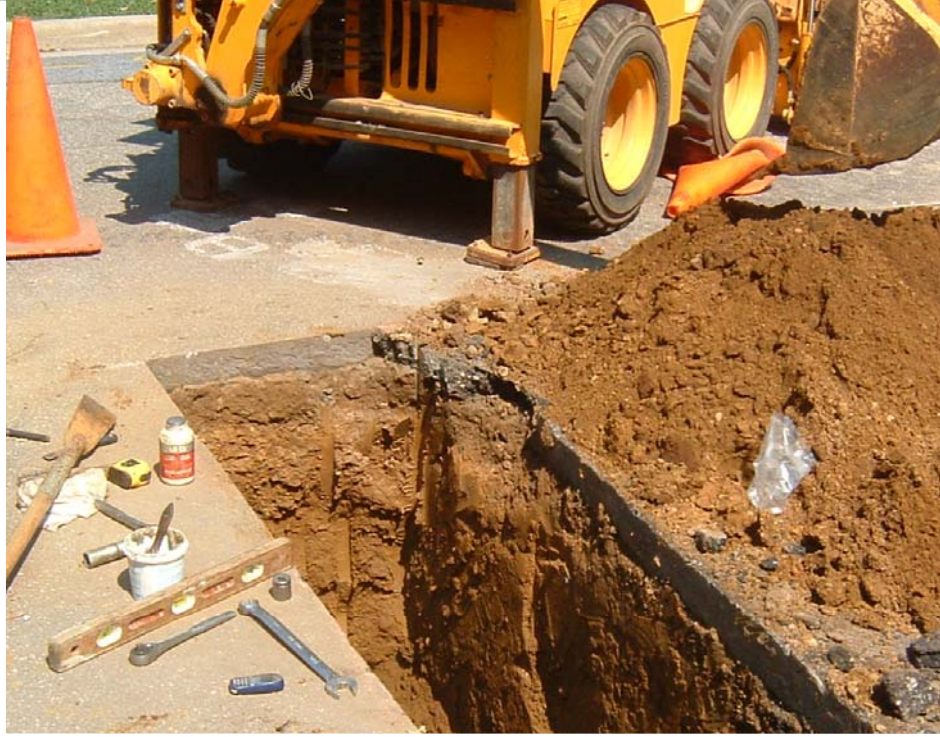
No Compost

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

Changes in soil type



Creating a soil profile with a Dutch auger



Adjacent constructions can reveal soil types and issues

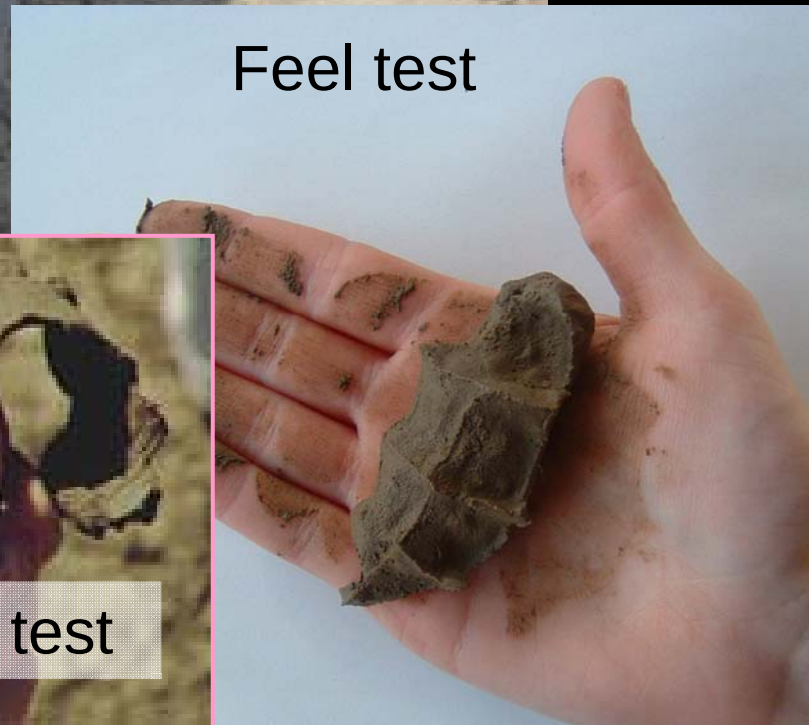
Clayey or silty soils?

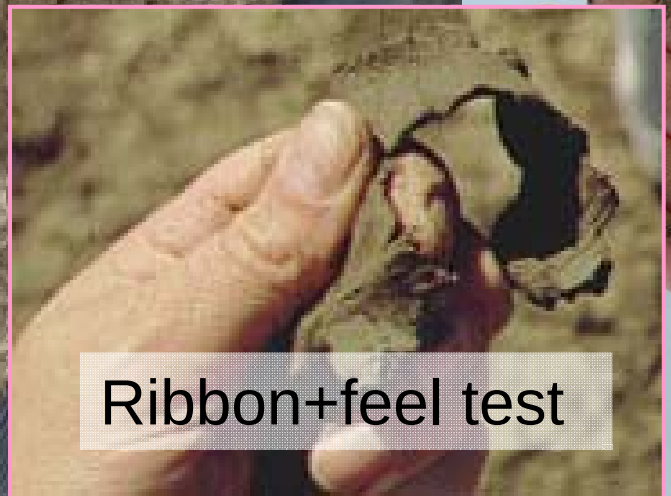
Shoe test

The harder to clean your shoes, tools, trucks; the greater the % clay

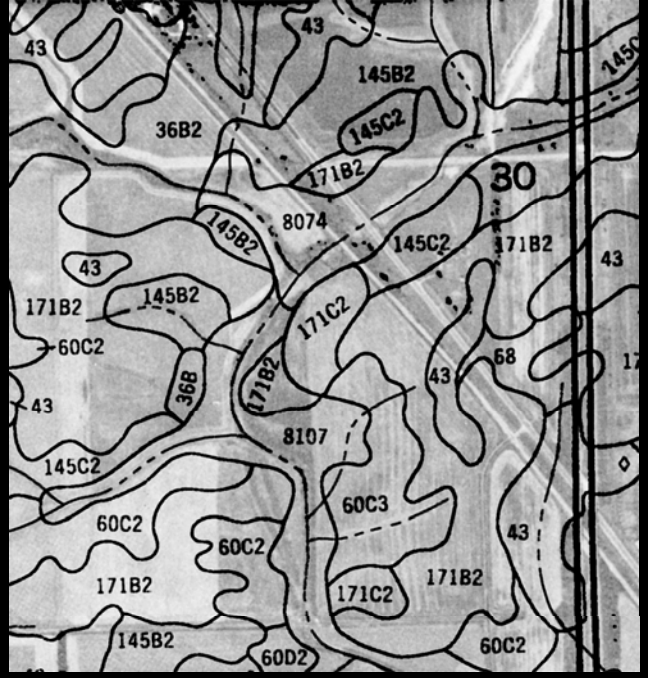
Truck test

Feel test





Ribbon+feel test



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

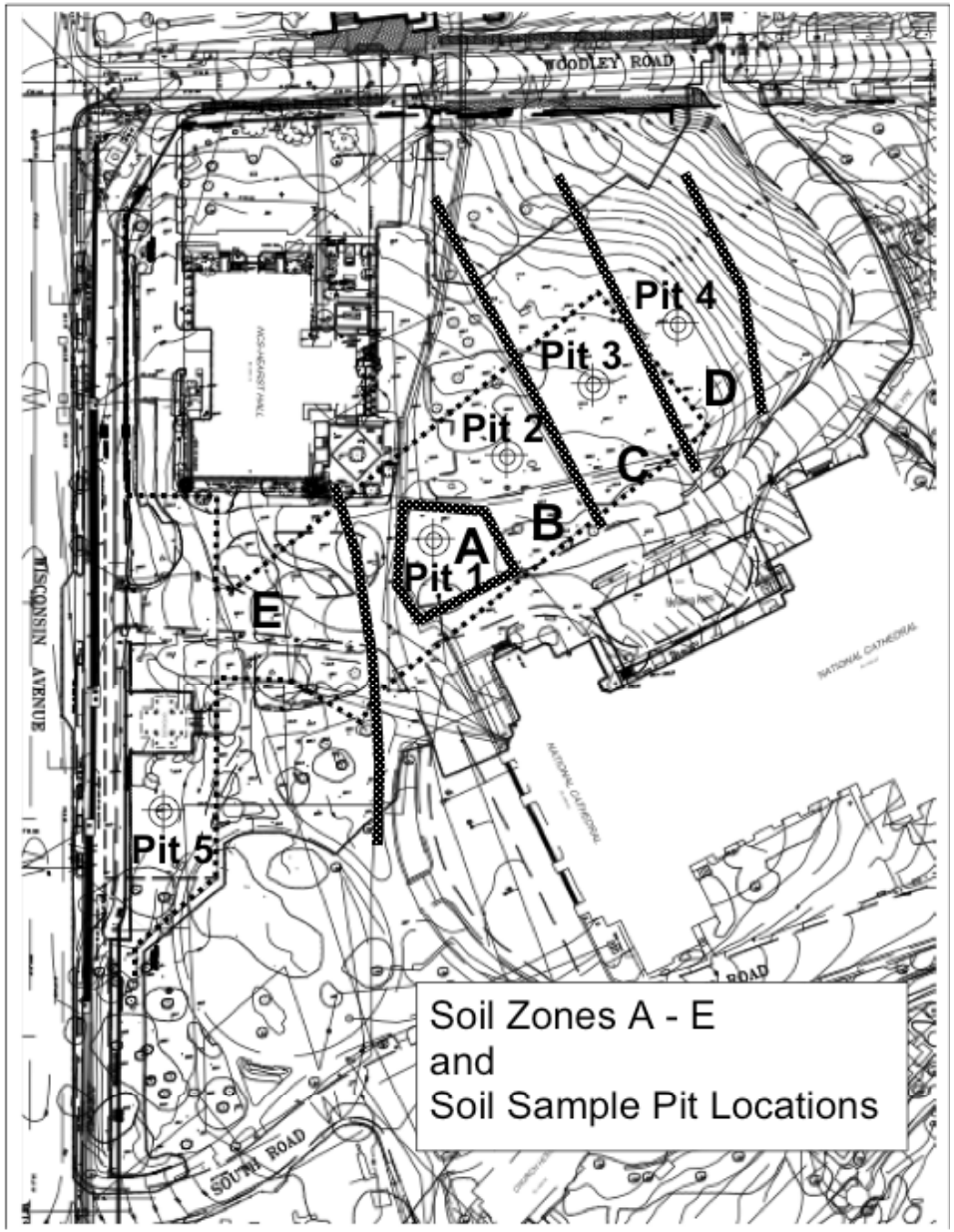
Under old trees, at property lines, cemeteries, parks etc.

Use this to find remnant soils.

Constantly smell the soil! Sour odor indicates poor drainage

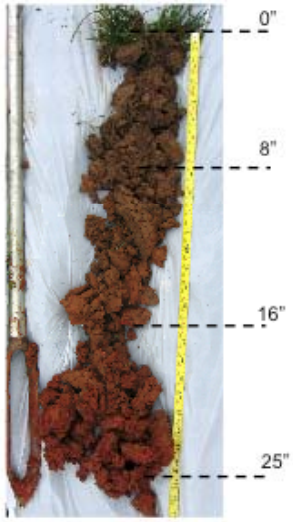
Grey color, poorly draining soil

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

What Next?

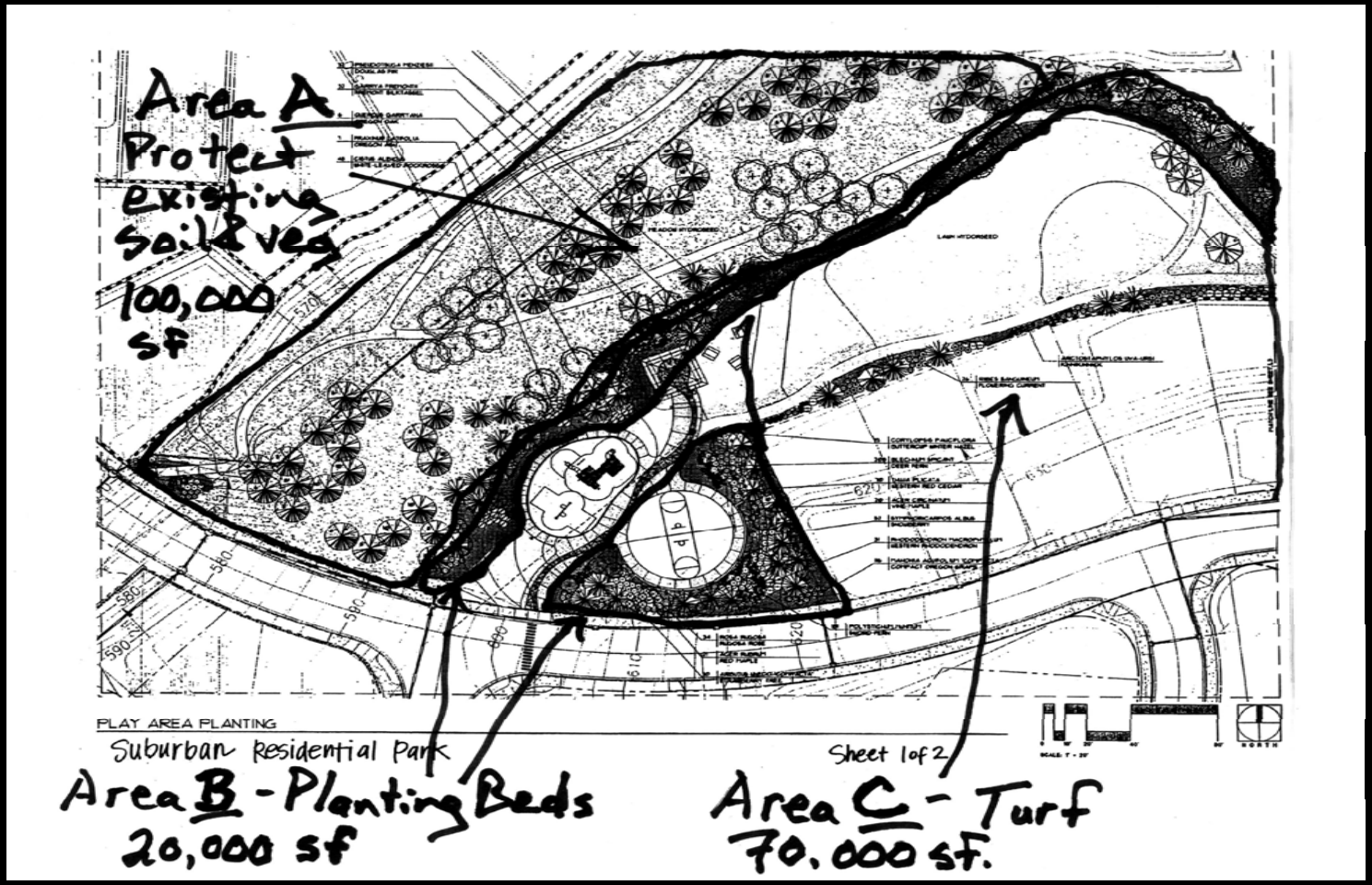
preview of next soil class section,

“Preserving, Restoring & Maintaining Healthy Soils”

Develop a “Soil Management Plan”

step 1: Identify & map

- Healthy soil areas as “vegetation and soil protection zones”
- Disturbed areas needing different soil restoration treatments

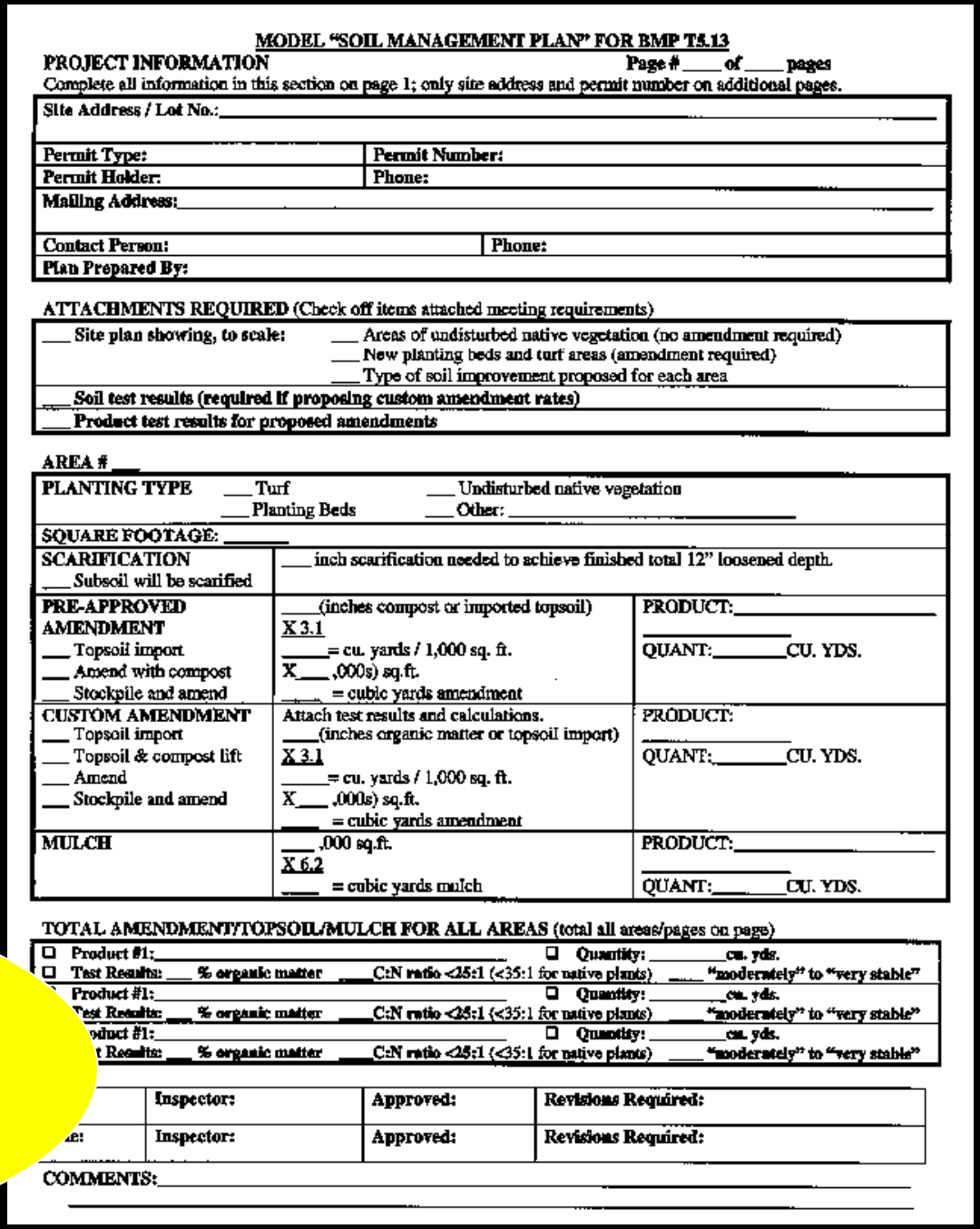


Soil Management Plan

step 2:
Compute compost amendment or amended topsoil and mulch needed for each area

This form is in the Building Soil Manual *at* www.BuildingSoil.org

(see pages 8-13)



MODEL "SOIL MANAGEMENT PLAN" FOR BMP T5.13

PROJECT INFORMATION Page # ____ of ____ pages

Complete all information in this section on page 1; only site address and permit number on additional pages.

Site Address / Lot No.:	
Permit Type:	**Permit Number:**
Permit Holder:	**Phone:**
Mailing Address:	
Contact Person:	**Phone:**
Plan Prepared By:	

ATTACHMENTS REQUIRED (Check off items attached meeting requirements)

___ Site plan showing, to scale:	___ Areas of undisturbed native vegetation (no amendment required) ___ New planting beds and turf areas (amendment required) ___ Type of soil improvement proposed for each area
___ **Soil test results (required if proposing custom amendment rates)**	
___ **Product test results for proposed amendments**	

AREA # ___

PLANTING TYPE ___ Turf ___ Planting Beds	___ Undisturbed native vegetation ___ Other: _____	
SQUARE FOOTAGE: _____		
SCARIFICATION ___ Subsoil will be scarified	___ inch scarification needed to achieve finished total 12" loosened depth.	
PRE-APPROVED AMENDMENT ___ Topsoil import ___ Amend with compost ___ Stockpile and amend	____(inches compost or imported topsoil) X 3.1 _____= cu. yards / 1,000 sq. ft. X____ ,000s) sq.ft. _____ = cubic yards amendment	PRODUCT:_____ _____ QUANT:_____CU. YDS.
CUSTOM AMENDMENT ___ Topsoil import ___ Topsoil & compost lift ___ Amend ___ Stockpile and amend	Attach test results and calculations. ____(inches organic matter or topsoil import) X 3.1 _____= cu. yards / 1,000 sq. ft. X____ ,000s) sq.ft. _____ = cubic yards amendment	PRODUCT: _____ QUANT:_____CU. YDS.
MULCH	____ ,000 sq.ft. X 6.2 _____ = cubic yards mulch	PRODUCT:_____ _____ QUANT:_____CU. YDS.

TOTAL AMENDMENT/TOPSOIL/MULCH FOR ALL AREAS (total all areas/pages on page)

☐ Product #1:_____	☐ Quantity: _____cu. yds.
☐ Test Results: ___ % organic matter ___ C:N ratio <25:1 (<35:1 for native plants)	___ "moderately" to "very stable"
Product #1:_____	☐ Quantity: _____cu. yds.
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oduct #1:_____	☐ Quantity: _____cu. yds.
t Results: ___ % organic matter ___ C:N ratio <25:1 (<35:1 for native plants)	___ "moderately" to "very stable"

	Inspector:	**Approved:**	**Revisions Required:**
e:	**Inspector:**	**Approved:**	**Revisions Required:**

COMMENTS:_____

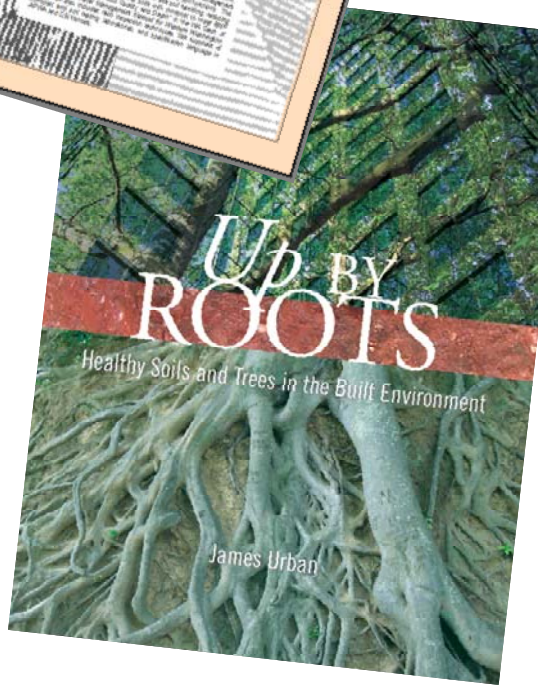
Resources to learn more:

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)*