Revegetation of Former Hydrocarbon and Brine Impacted Soils

An issue particular to hydrocarbon impacted soils: hydrophobicity

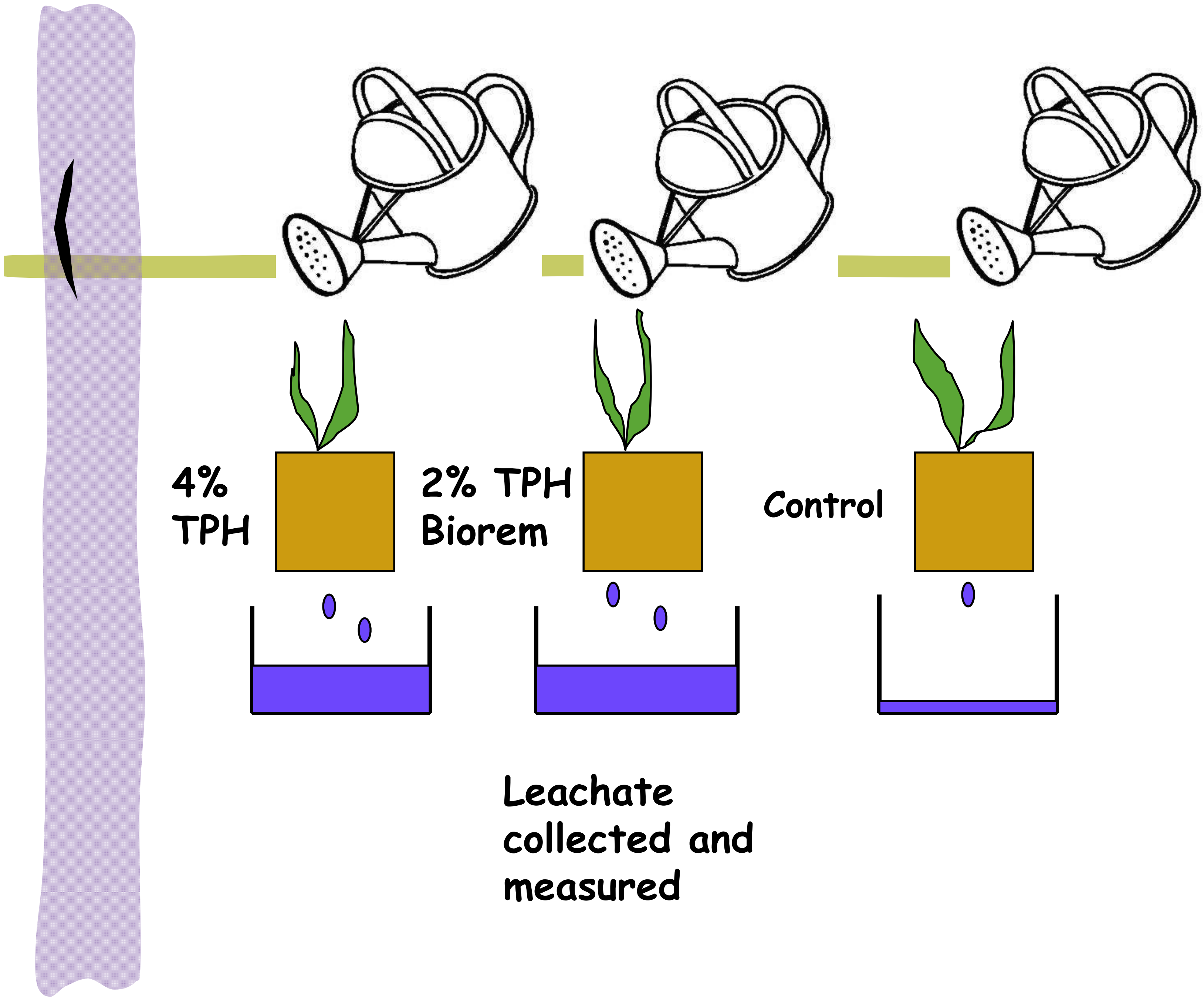
- Hydrophobicity is caused by the coating of soil particles with hydrophobic or "water repelling" organic matter

Water drops on hydrophobic soil

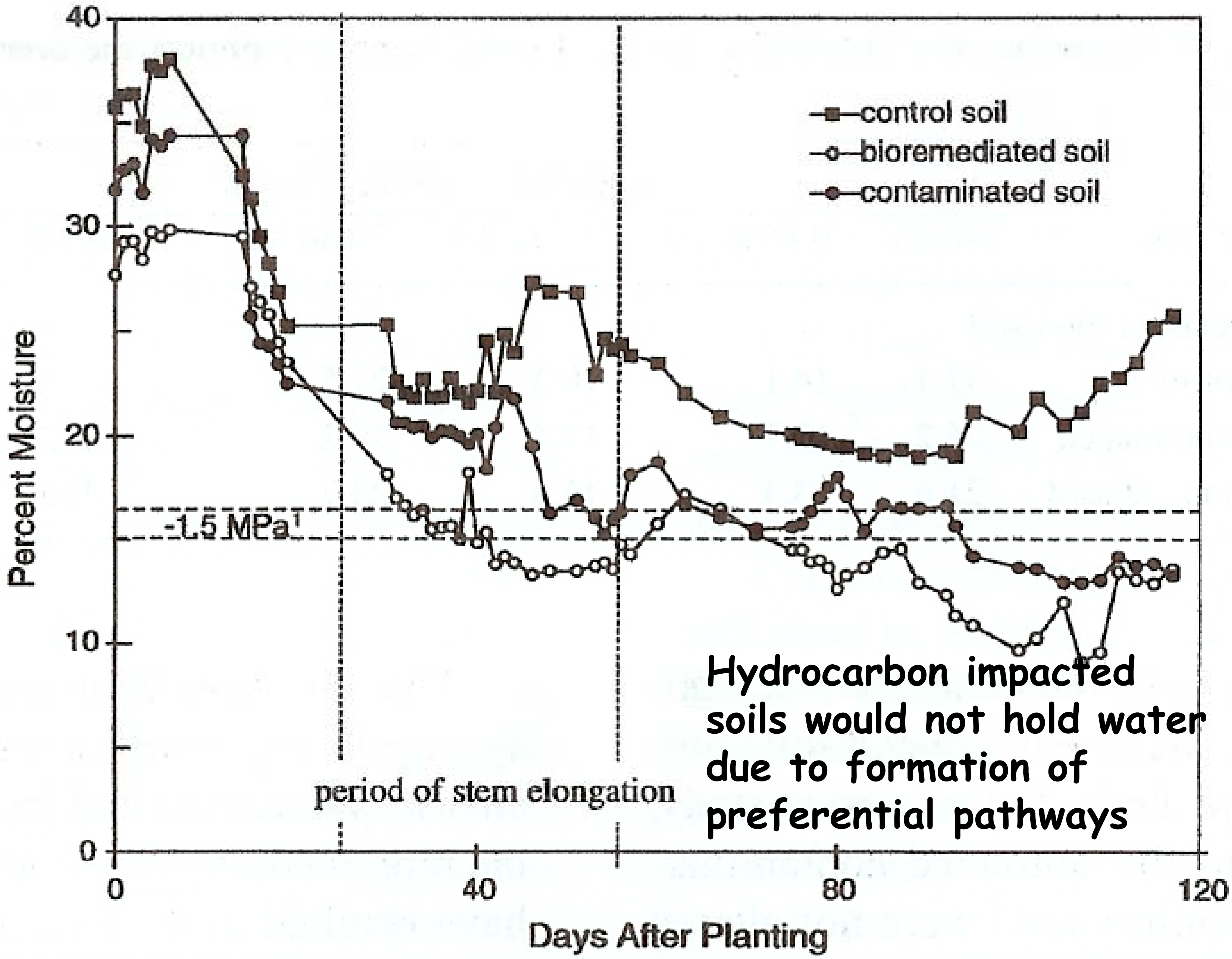
Hydrophobicity can inhibit revegetation

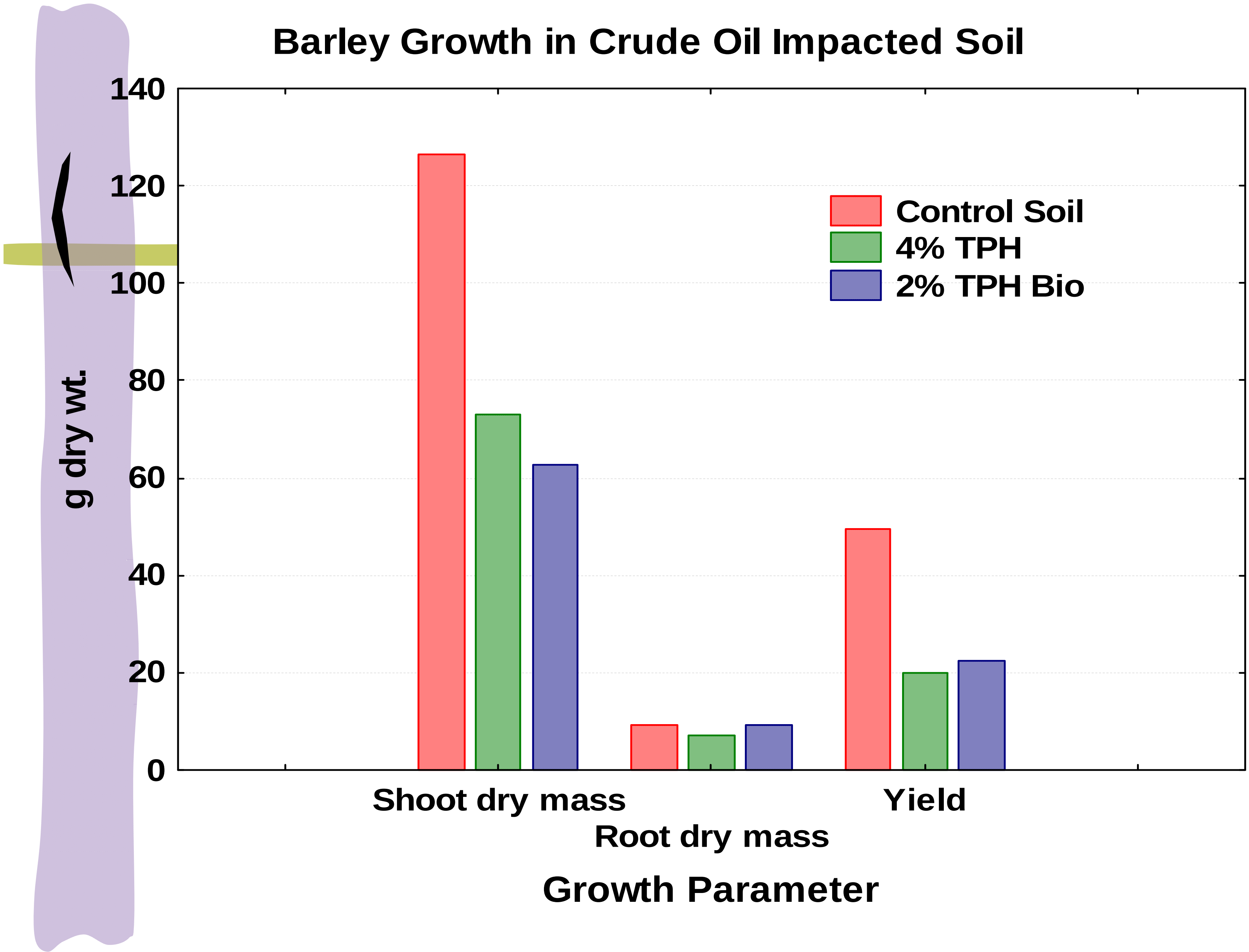
- Li et al. (1997) showed that hydrocarbon impacted soils failed to support healthy plant growth because the soil would not hold water (not because of any toxicity)
  - Contaminated soil contained 4% TPH
  - Bioremediated soil contained 2% TPH
  - Control soil with no hydrocarbon impact
  - All soils received the same watering protocol with collection of leachate

Li et al., Plant and Soil, **192**, 219-226 (1997)



4% TPH
2% TPH Biorem
Control
Leachate collected and measured


control soil
bioremediated soil
contaminated soil
-1.5 MPa¹
period of stem elongation
Percent Moisture
Days After Planting
0
10
20
30
40
0
40
80
120
Hydrocarbon impacted soils would not hold water due to formation of preferential pathways



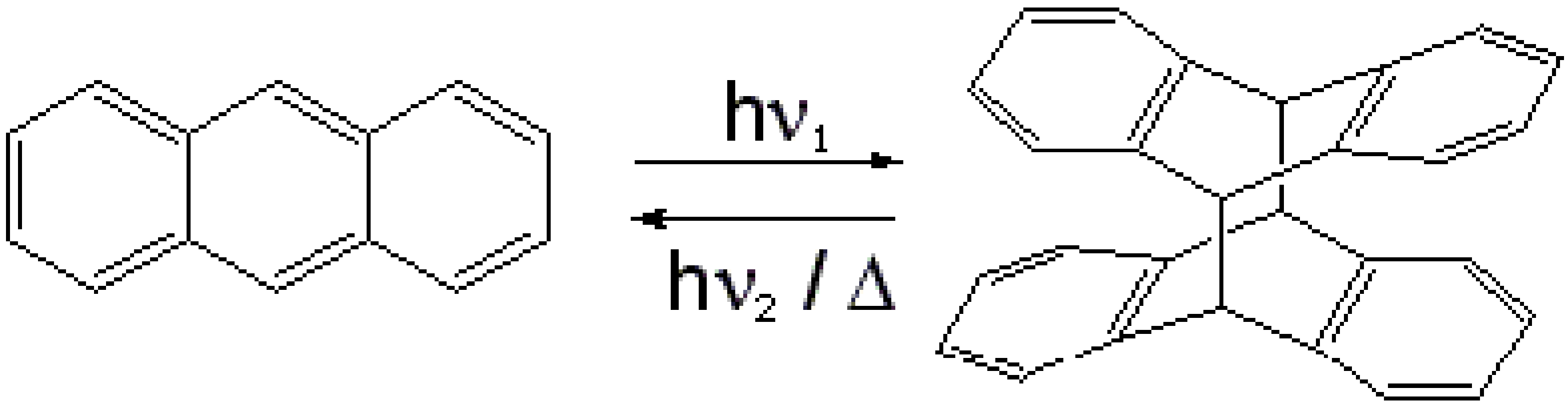
Barley Growth in Crude Oil Impacted Soil
g dry wt.
140
120
100
80
60
40
20
0
Control Soil
4% TPH
2% TPH Bio
Shoot dry mass
Root dry mass
Yield
Growth Parameter

When is hydrophobicity likely to be a problem?

- Roy et al. (2003), in a study of a old weathered oil-impacted sites in Alberta, reported that hydrophobicity was associated with some, but not all, crude oil spill sites
- Hydrophobicity is probably a product of a combination of circumstances including:
  - **properties of the crude oil (greater proportions of heavies and waxy hydrocarbons)**
  - **dryness of the soil at the time of first contact with hydrocarbon**
  - **prolonged exposure to hot dry weather and ultraviolet light**

Roy et al., J. Environmental Quality, **32**, 583-590 (2003)

An example of UV-induced chemical reactions



These photo-induced reactions increase the likelihood of strong interactions between hydrocarbons and mineral particles and SOM. Result is:

- Increase in hydrophobicity
- Decrease in apparent TPH (poor extraction of photoproducts)

Reference

How do we measure hydrophobicity?

- Molarity of Ethanol Droplet (MED) test
  - Hand sieve soil to a fineness of < 1 mm removing any rock or plant fragments
  - Dry the soil at 105 °C for 24 hrs
  - Transfer soil to a shallow container and level the soil gently
  - Use a medicine dropper to gently apply drops of water with increasing concentrations of ethanol to the soil surface, each time assessing the amount of time required for total absorption
  - The MED is the molarity of the least concentrated ethanol solution that is absorbed in under 10 sec

Reference

Preparation of ethanol solutions

*Dilute the indicated volume of 100 proof vodka to a total of 50 mL with distilled water.

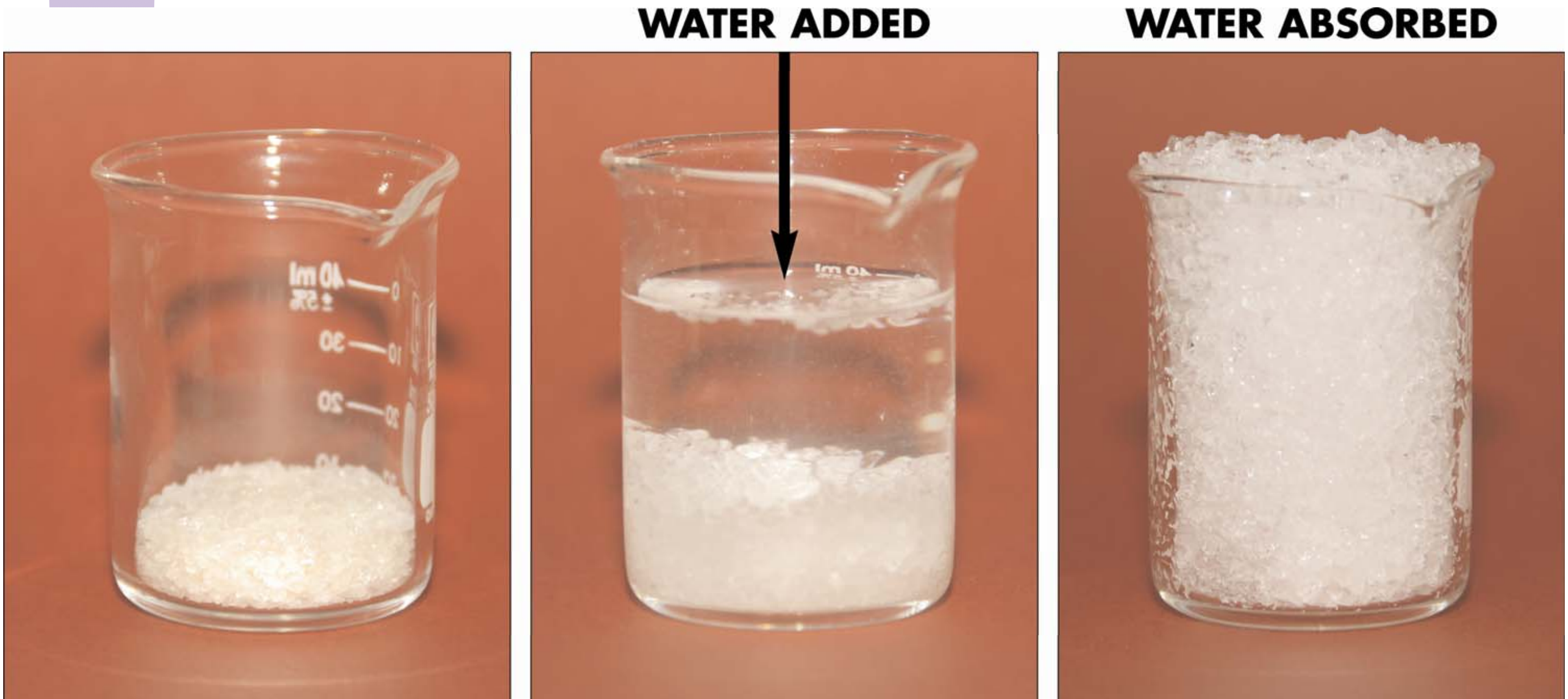
Molarity (M)	mL Vodka*	Molarity (M)	mL Vodka*
0	0	3.2	18.7
0.2	1.2	3.4	19.8
0.4	2.3	3.6	21.0
0.6	3.5	3.8	22.2
0.8	4.7	4.0	23.3
1.0	5.8	4.2	24.5
1.2	7.0	4.4	25.7
1.4	8.2	4.6	26.8
1.6	9.3	4.8	28.0
1.8	10.5	5.0	29.2
2.0	11.7	5.2	30.3
2.2	12.8	5.4	31.5
2.4	14.0	5.6	32.6
2.6	15.2	5.8	33.8
2.8	16.3	6.0	35.0
3.0	17.5	6.2	36.1

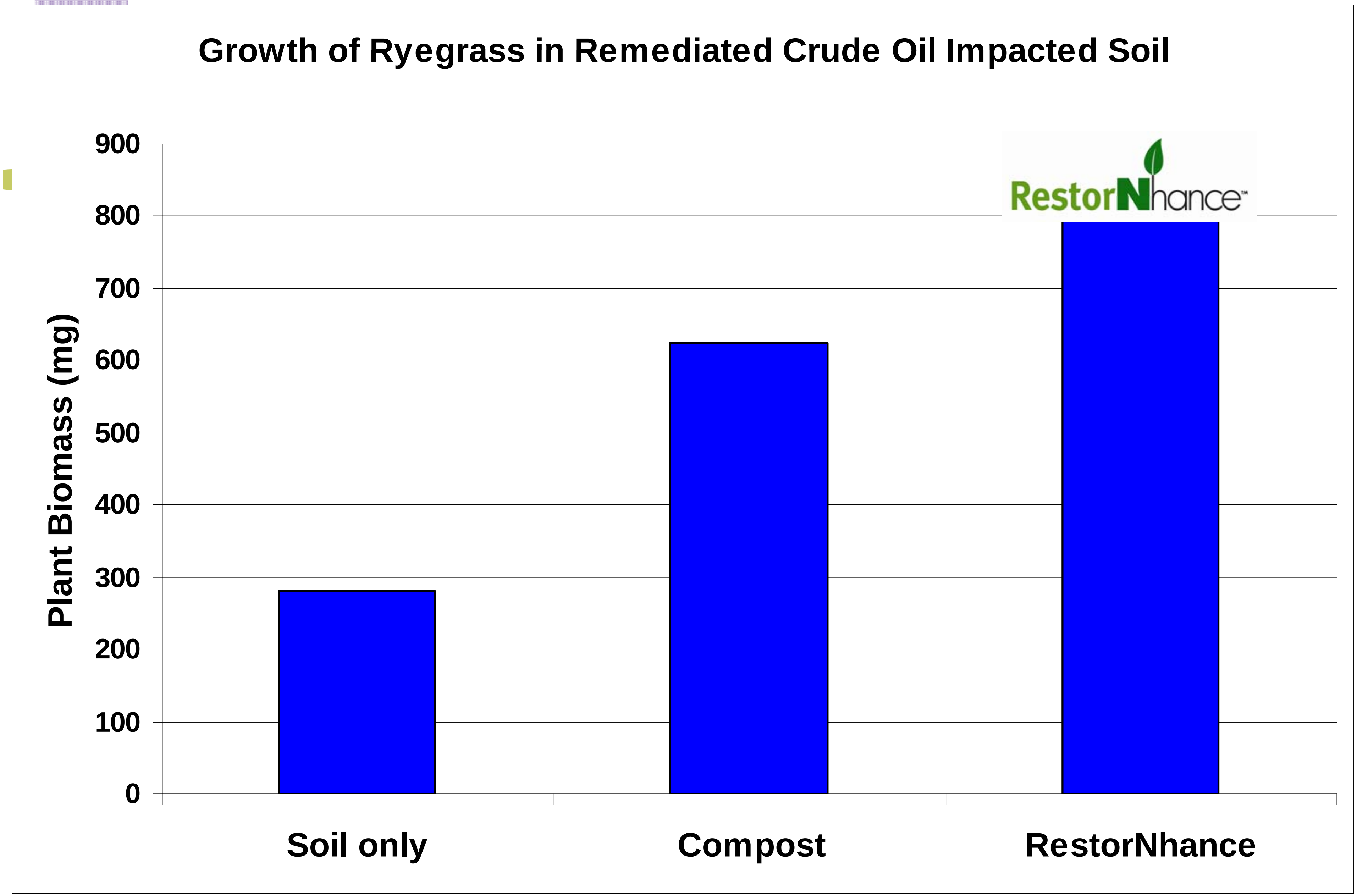
What can we do about hydrophobicity?

- Hydrophobicity is counteracted by hydrophilic organic matter (hay or composted manure, for example) and hydrogels
  - Increases water holding capacity of the soil
  - Increases contact of water with hydrophobic soil particles making them more likely to wet
- BioNhance during the remediation phase or
- RestorNhance during revegetation of hydrophobic but bioremediated soils
  - Both sources of hydrogels:

The power of hydrogels

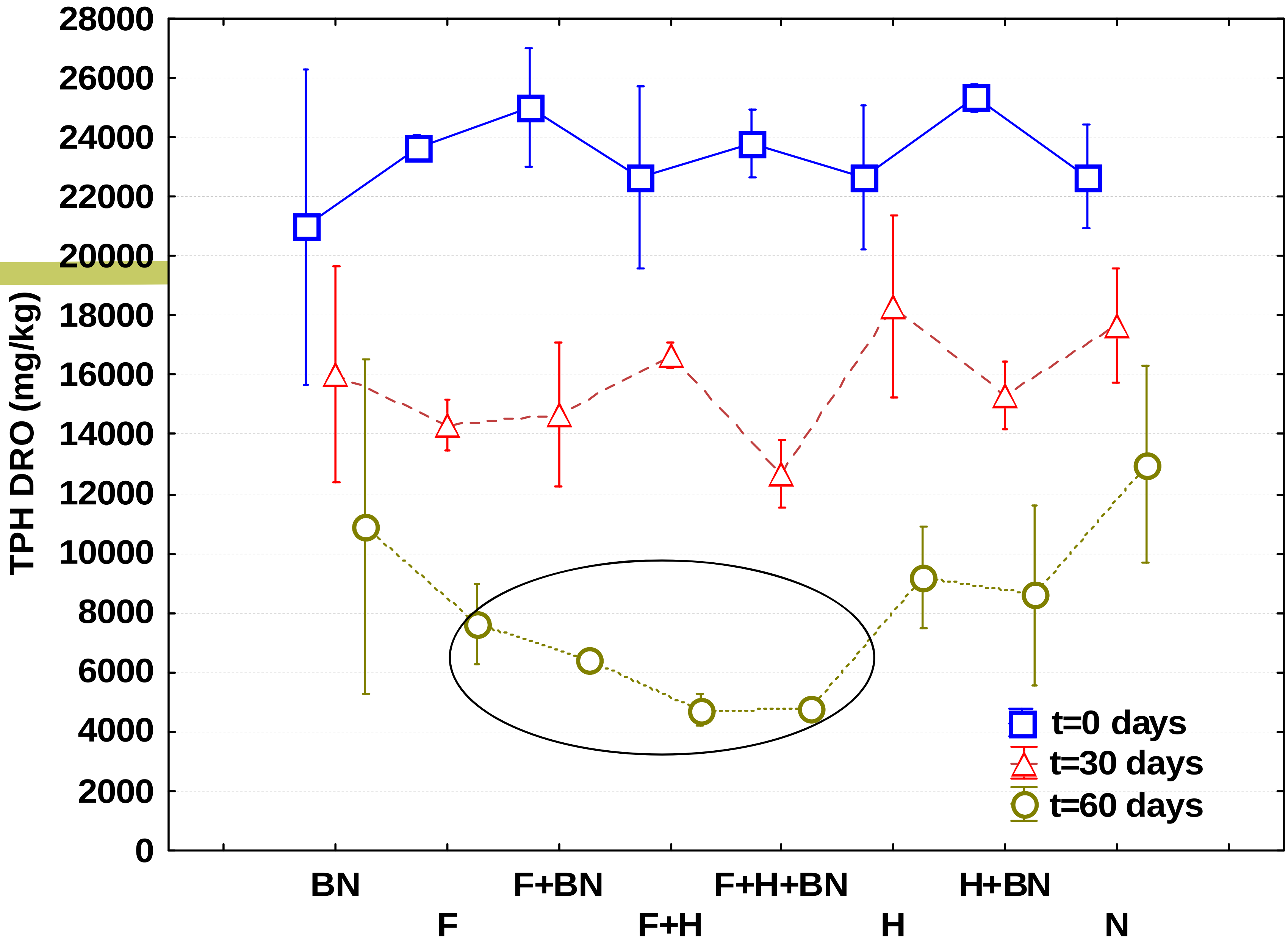
RestorNhance™




Growth of Ryegrass in Remediated Crude Oil Impacted Soil
Plant Biomass (mg)
900
800
700
600
500
400
300
200
100
0
RestorNhance
Soil only
Compost
RestorNhance

RestorNhance field test
Initiated July 2008

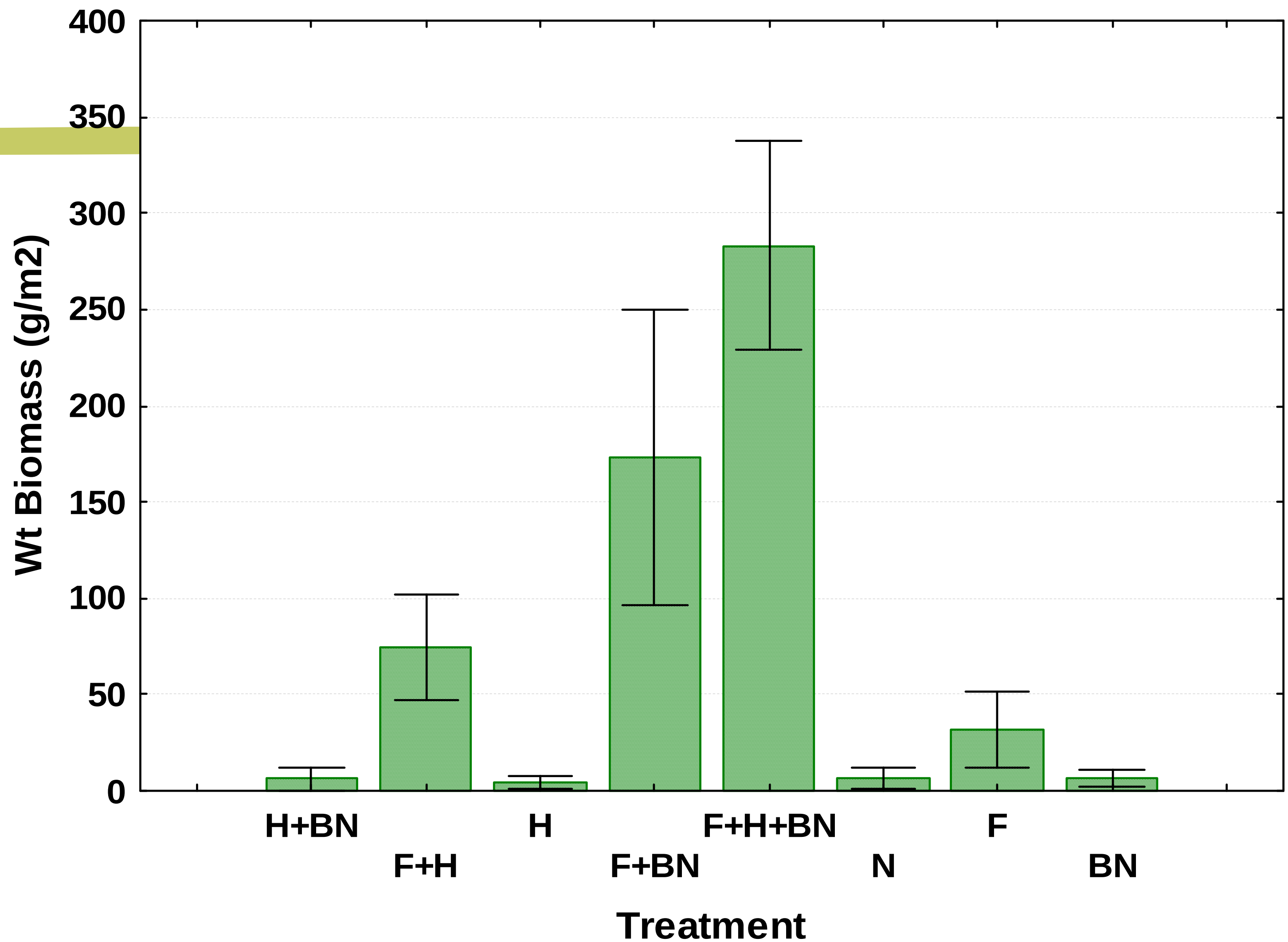
- Randomized block design with at least triplicate treatments
  - 8 ft by 8 ft plots
  - 9 gal of 42 API crude oil applied and tilled in
  - Amendments for treatments applied and plots re-tilled
  - Equivalent of one inch rainfall applied at startup
  - Reapplication of amendments at 30 and 60 days
- Treatments
  - Hay
  - Fertilizer
  - Hay + Fertilizer
  - RestorNhance
  - RestorNhance + Hay
  - RestorNhance + Fertilizer
  - RestorNhance + Hay + Fertilizer
  - None
- Analysis
  - TPH DRO at 0, 30, and 60 days
  - Plant above ground biomass and percent coverage in Spring 2009



BN= RestorNhance

F=fertilizer, H=hay, N=no treatment

Plant aboveground biomass Spring 2009



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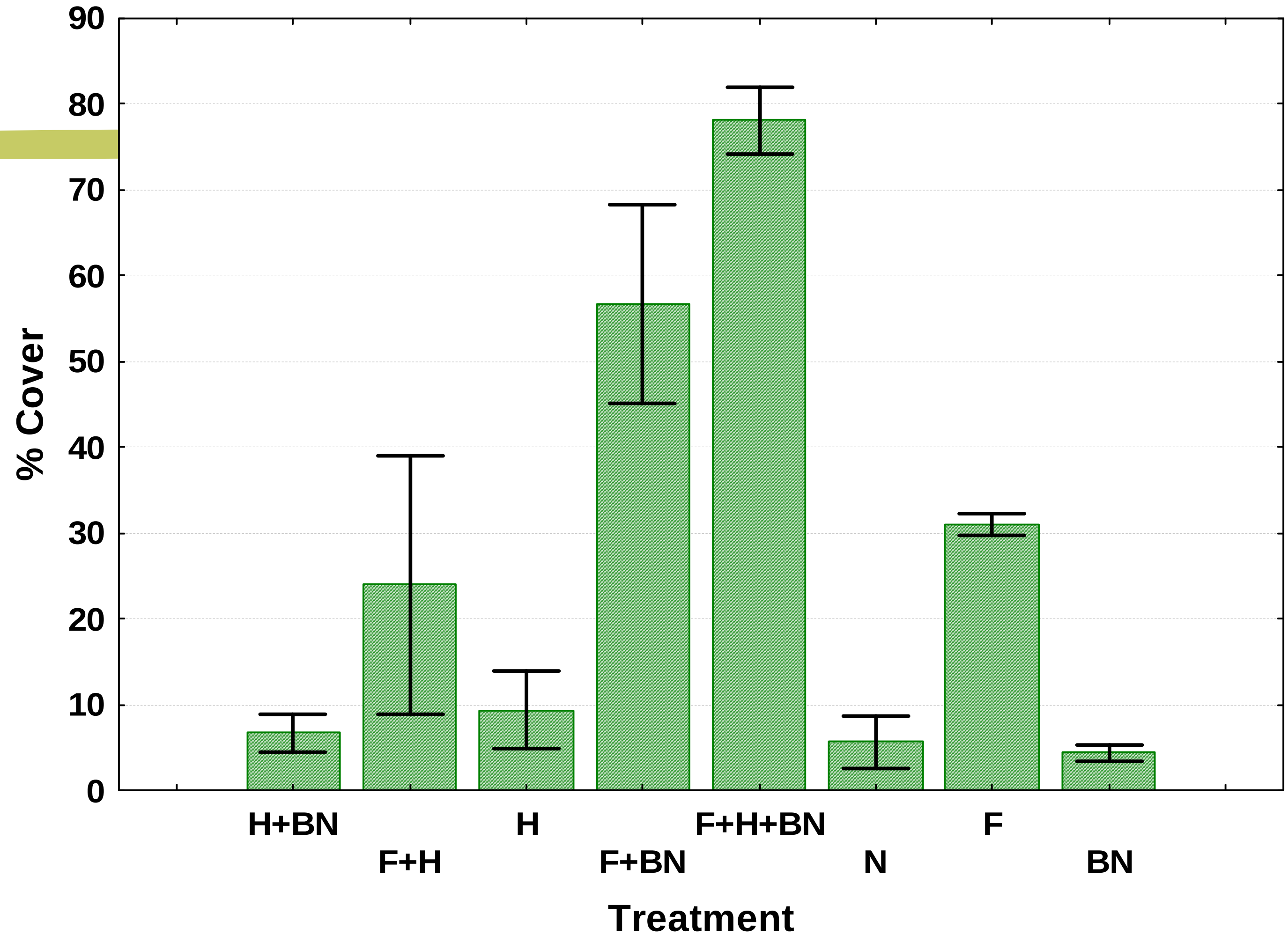
Plant cover
Spring 2009



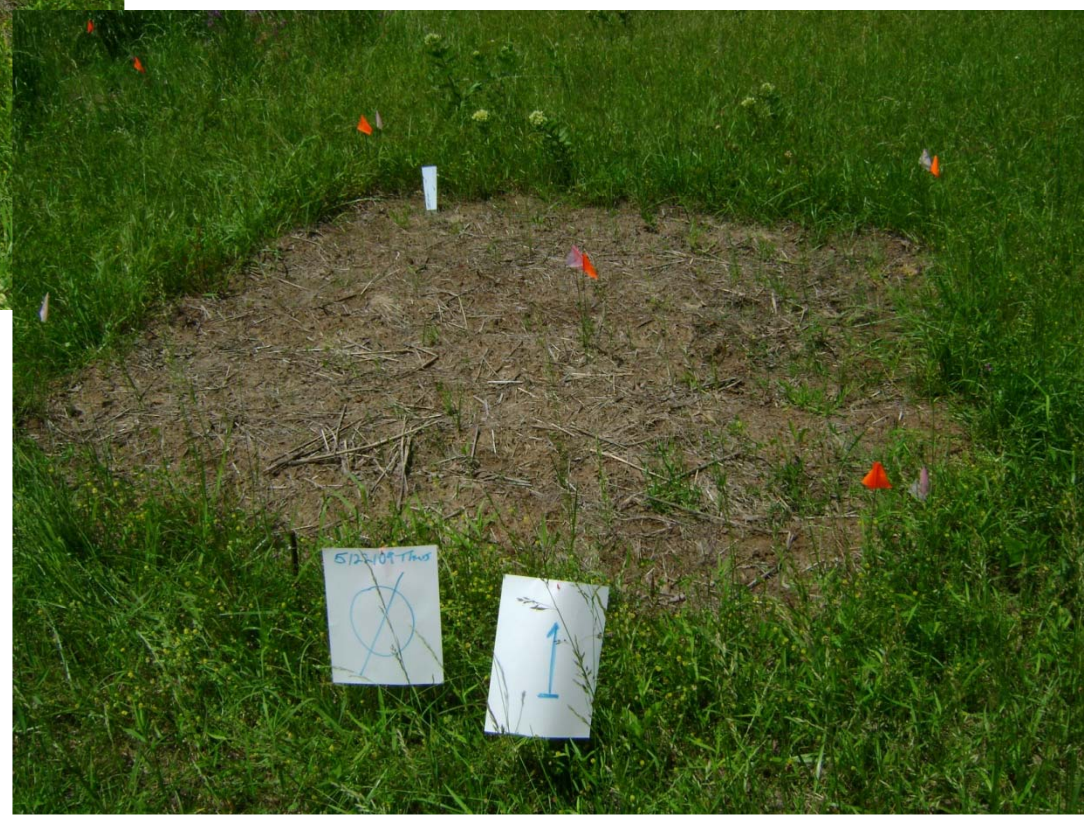
BN = RestorNhance

F=fertilizer, H=hay, N=no treatment

No treatment

Fertilizer only

Hay + RestorNhance



Hay and fertilizer

RestorNhance™ + hay and fertilizer

Revegetation of former brine impacted soils

The ultimate goal of the brine remediation process

Even if you dig and haul you still have to revegetate

Revegetation

- Natural revegetation?
  - Requires adequate moisture
    - Rainfall relative to evaporation potential
  - Requires desired vegetation immediately adjacent to site
  - If and when the desired vegetation makes up > 20% of the plant canopy cover then natural revegetation with the desired plant community is possible
  - Weed management strategies may be required to give the desired plants a foothold in the site
    - Frequent monitoring
    - Hand pulling of weeds
    - Spot treatment with herbicides
    - Transplanting of desired vegetation

Reference

Correcting weed infestations

- Till site in late fall to encourage maximum germination of weed seeds
- A few weeks later apply a non-selective herbicide to kill newly emerging weeds
- Following herbicide treatment plant seeds of fall dormant grasses
- The following spring the remaining weed seeds and seeded grasses should emerge with adequate moisture; if grass seedlings survive to midsummer apply a broadleaf herbicide
- Contact local experts for herbicide recommendations and rates specific to your site conditions

Reseeding for revegetation

- Establish goals in consultation with landowner and regulator
  - Restore forage crops?
  - Restore agricultural productivity?
  - Restore native plant community?
  - Quick revegetation for erosion control?
  - Halophytes?

Reseeding a remediated site, replacement soil, or other restoration site

- Assess the overall quality of the soil
  - Primary and secondary plant nutrients
    - Use an ag lab to provide recommendations for specific plant community desired
  - Bulk density (g dry soil/cm^3)
    - Ideal: 1.4
    - Acceptable: 1.2 – 1.6
  - Soil texture
    - Match plants with soil texture
  - Organic matter
    - Ideal: > 3%
    - Acceptable: > 2%
  - pH
    - Ideal: 6.5 - 7.5
    - Acceptable: 5.5 – 8.5

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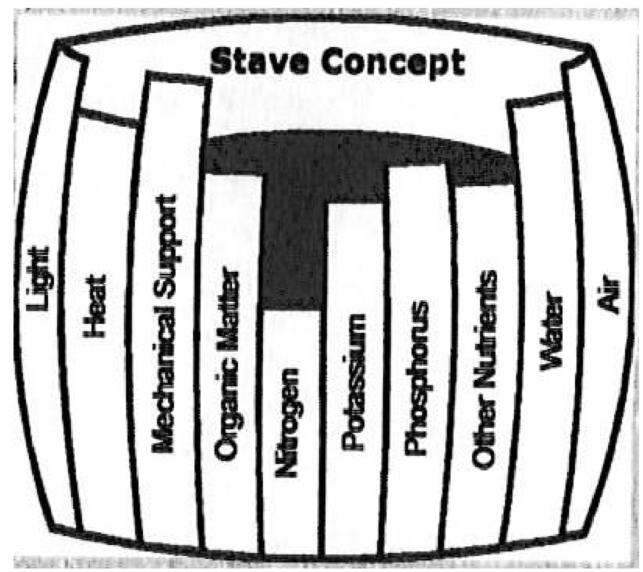

Plant Nutrients

Washington State University
World Class. Face to Face.

Major Nutrients

- Nitrogen
- Phosphorus
- Potassium
- Calcium
- Magnesium
- Sulfur

Micronutrients

- Boron
- Iron
- Manganese
- Zinc
- Copper
- Chloride
- Molybdenum

Reference

RELATIVE STATUS							
Element	Application	Units	V. Low	Low	Medium	High	V. High
pH	All,	5.0 – 7.0 is normally acceptable. Some species benefit from more acid conditions.					
pH	micro-irrig. blockage		<6.5	6.5-7.2	7.2-7.6	7.7-8.0	>8.0
Nitrogen, Total (N)	All	ppm	<18	19-36	37-54	55-90	>90
Nitrate-N (NO_3-N)	All	ppm	<15	16-30	31-45	46-75	>75
Ammonium-N (NH_4-N)	All	ppm	<3	4-6	7-9	10-15	>15
NH_4-N + NO_3-N	Hydroponics	ppm	<5	6-13	14-21	22-30	>30
Phosphorus (P)	All	ppm	<1	1-1.9	2-2.9	3-5	>5
Potassium (K)	All	ppm	<3	3.1-4.5	4.6-6.0	6.1-10.0	>10
Calcium (Ca)*	All	ppm	<40	41-80	81-120	121-150	>150
Magnesium (Mg)	All	ppm	<8	9-16	17-24	25-30	>30
Sulfate-S (SO_4-S)	All	ppm	<24	25-50	51-240	241-300	>300
Boron (B)**	Greenhouse, Nursery	ppm	<0.25	0.26-0.5	0.51-0.8	0.81-2.0	>2.0
Boron (B)**	Field crops	ppm	<0.75	0.76-1.17	1.18-1.6	1.61-2.0	>2.0
Boron (B)	Hydroponics	ppm	<1.0	1.1-1.25	1.26-1.6	1.61-2.0	>2.0
Copper (Cu)	All	ppm	<0.05	0.06-0.10	0.11-1.20	0.21-0.30	>0.30
Iron (Fe)	All	ppm	<0.20	0.21-0.30	0.31-0.40	0.41-0.50	>0.50
Iron (Fe)	micro-irrig. blockage	ppm	<0.20	0.21-0.63	0.64-1.0	1.1-1.5	>1.5
Manganese (Mn)	All	ppm	<0.50	0.51-0.75	0.76-1.0	1.1-2.0	>2.0
Manganese (Mn)	micro-irrig. blockage	ppm	<0.10	0.11-0.57	0.58-1.0	1.1-1.5	>1.5
Molybdenum (Mo)	All	ppm	<0.005	.006-0.01	0.011-.020	.021-0.05	>0.05

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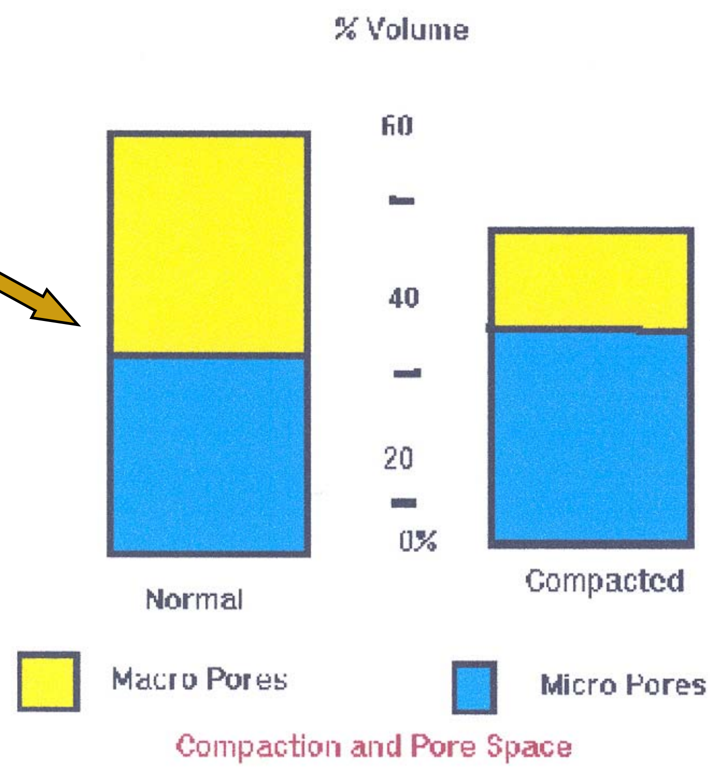
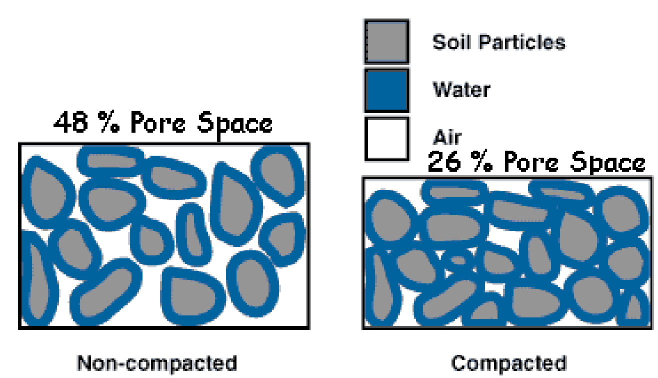
The bulk soil density is the weight of oven dry soil/volume of the soil before drying

Low bulk soil density



High bulk soil density



Low Medium High

Bulk soil density

The effects of soil compaction may persist for decades

Historic bison wallow (from the 19th century) in tallgrass prairie in Oklahoma

Ideal soil bulk densities and root growth limiting bulk densities for soils of different textures

Soil texture	Ideal bulk densities	Bulk densities that may affect root growth	Bulk densities that may restrict root growth
	g/cm^3		
Source: generalized from USDA-NRCS soil quality test kit guide.			
Sand, loamy sand	<1.60	1.70	>1.80
Sandy loam, loam, sandy clay loam, clay loam, silt, silt loam, silty clay loam	<1.40	1.60	>1.75
Sandy clay, silty clay, clay	<1.10	1.50	>1.60

Measuring bulk soil density

- Remove vegetation from the soil surface
- Push a pre-weighed sampling can of known volume into the soil. If it is difficult to push into the soil, place a piece of wood over the can and hit the wood with a hammer. If necessary wet the soil to make it easier to drive into the ground. Drive the sampling can into the ground until soil just starts to come out of the small hole in the bottom of the can.

Measuring bulk soil density

- Using a trowel or shovel dig around the can in order to remove it from the soil
- Trim the soil from the top of the can and around the edges of the can so that the volume of the soil is the same as the volume of the can; cover the can with a lid and label and ship to ag lab

Reducing bulk soil density

- Ripping and secondary tillage*
- Incorporation of organic matter (compost and biodegradable organic matter)*
- Limit access to livestock
- Keep vehicles off the site
- With time natural mechanisms of decreasing bulk soil density:
  - Freeze-thaw cycles
  - Actions of soil animals

*If revegetation efforts immediately follow successful remediation these steps may be unnecessary.

Reseeding a remediated site, replacement soil, or other restoration site

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  - **Soil texture**
    - **Match plants with soil texture**
  - Organic matter
    - Ideal: > 3%
    - Acceptable: > 2%
  - pH
    - Ideal: 6.5 - 7.5
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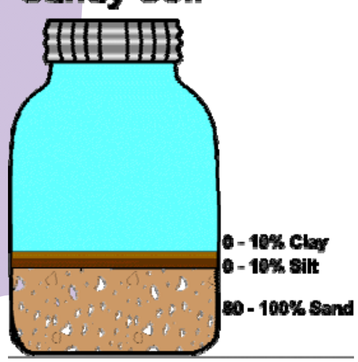
What kind of soil do you have?

Sandy

Feels gritty; non-cohesive – does not stick together in a mass unless it is very wet.

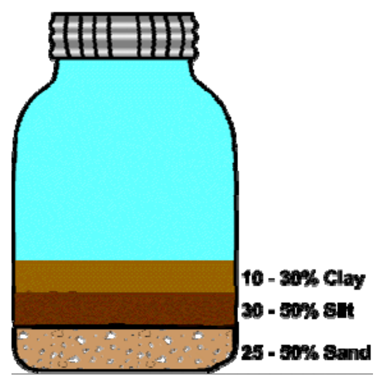
Sandy Soil



Loam

Does not feel gritty;
floury feel;
smooth;
wet silt does not exhibit stickiness

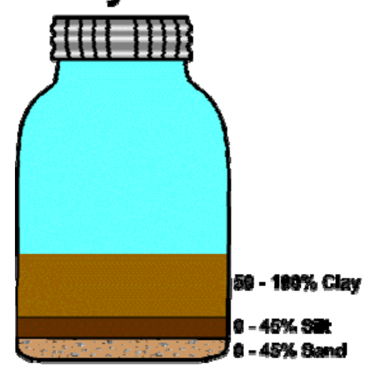
Loam Soil



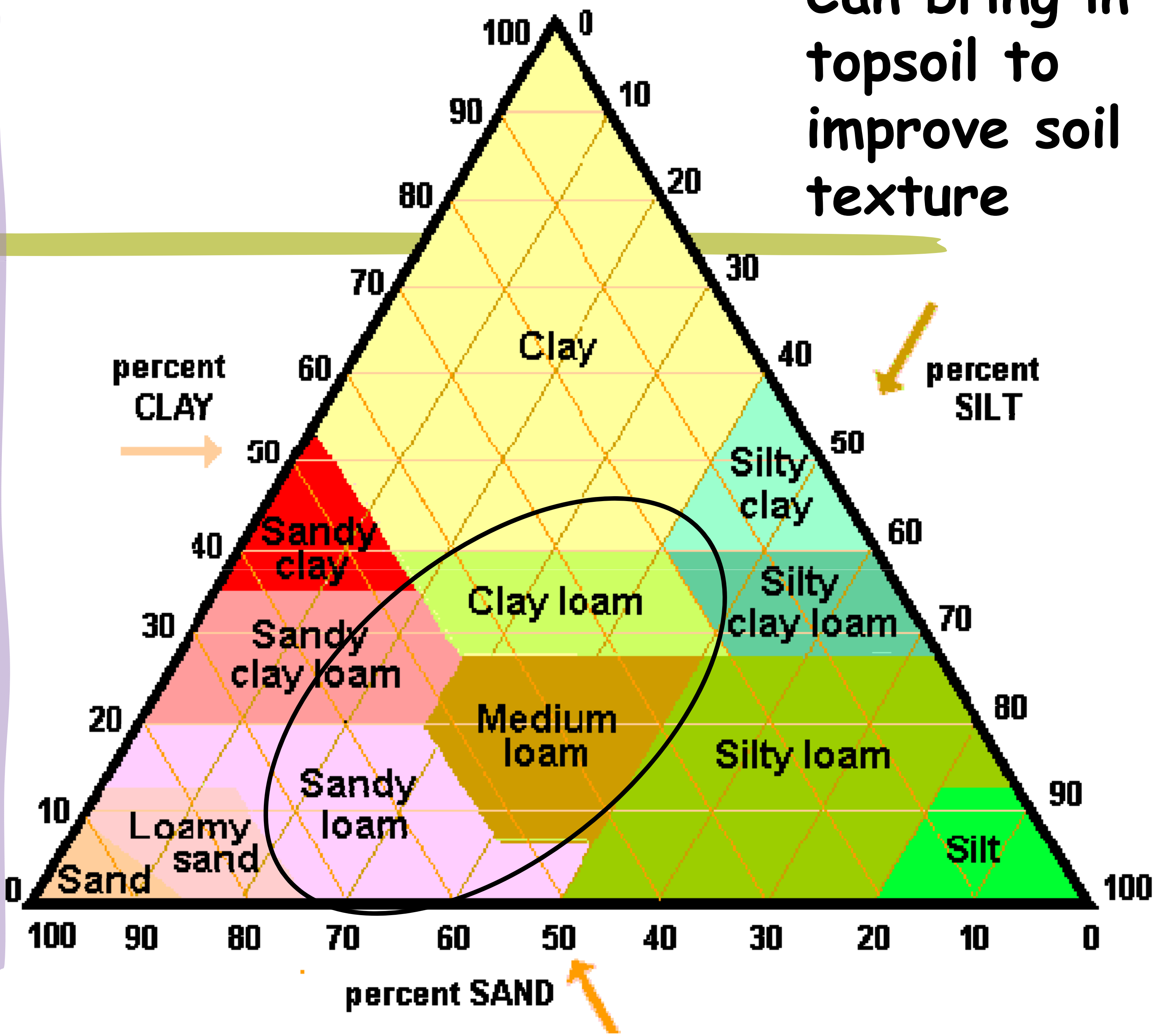
Clay

Wet clay is very sticky; easily formed into long ribbons

Clay Soil



Can bring in topsoil to improve soil texture



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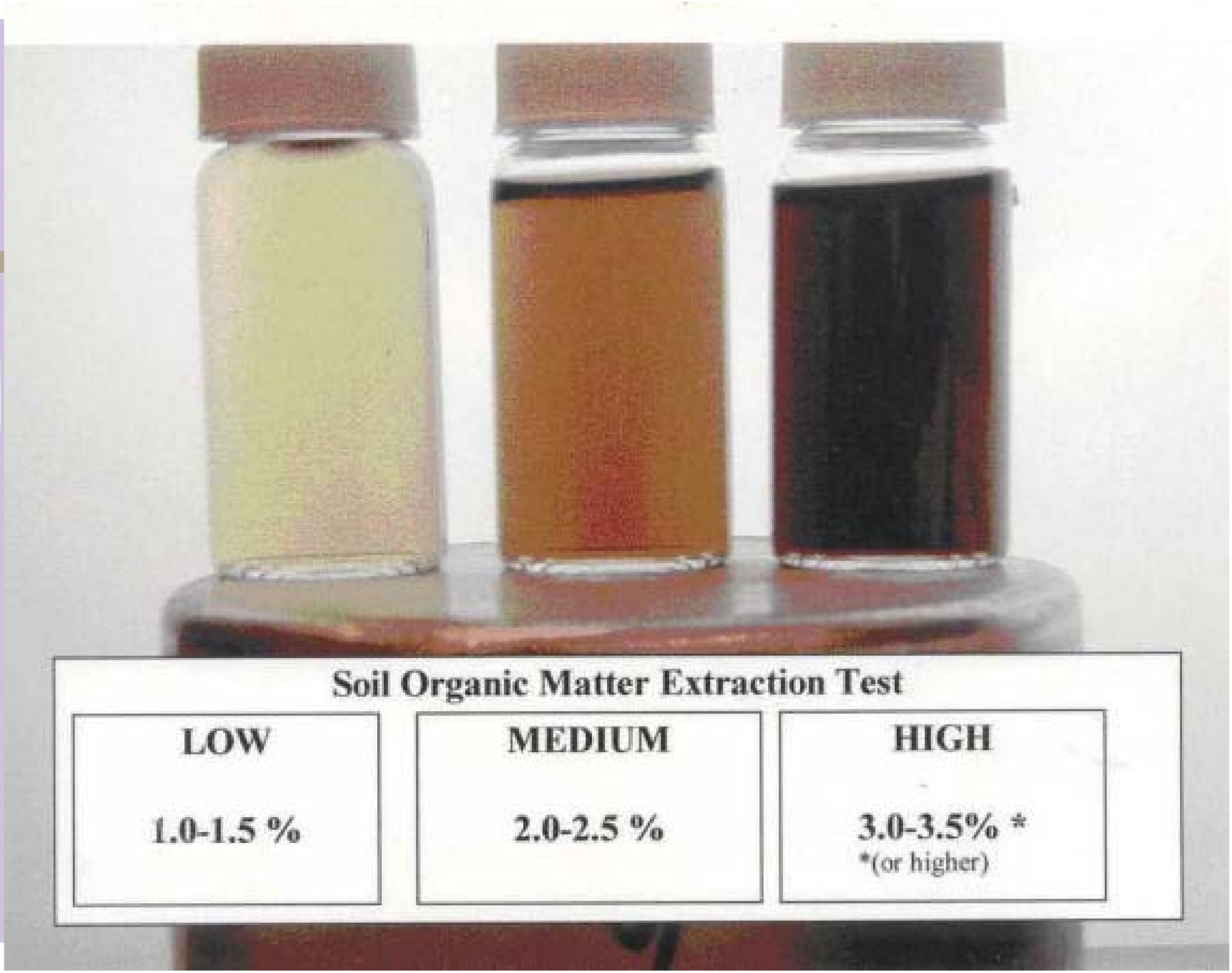
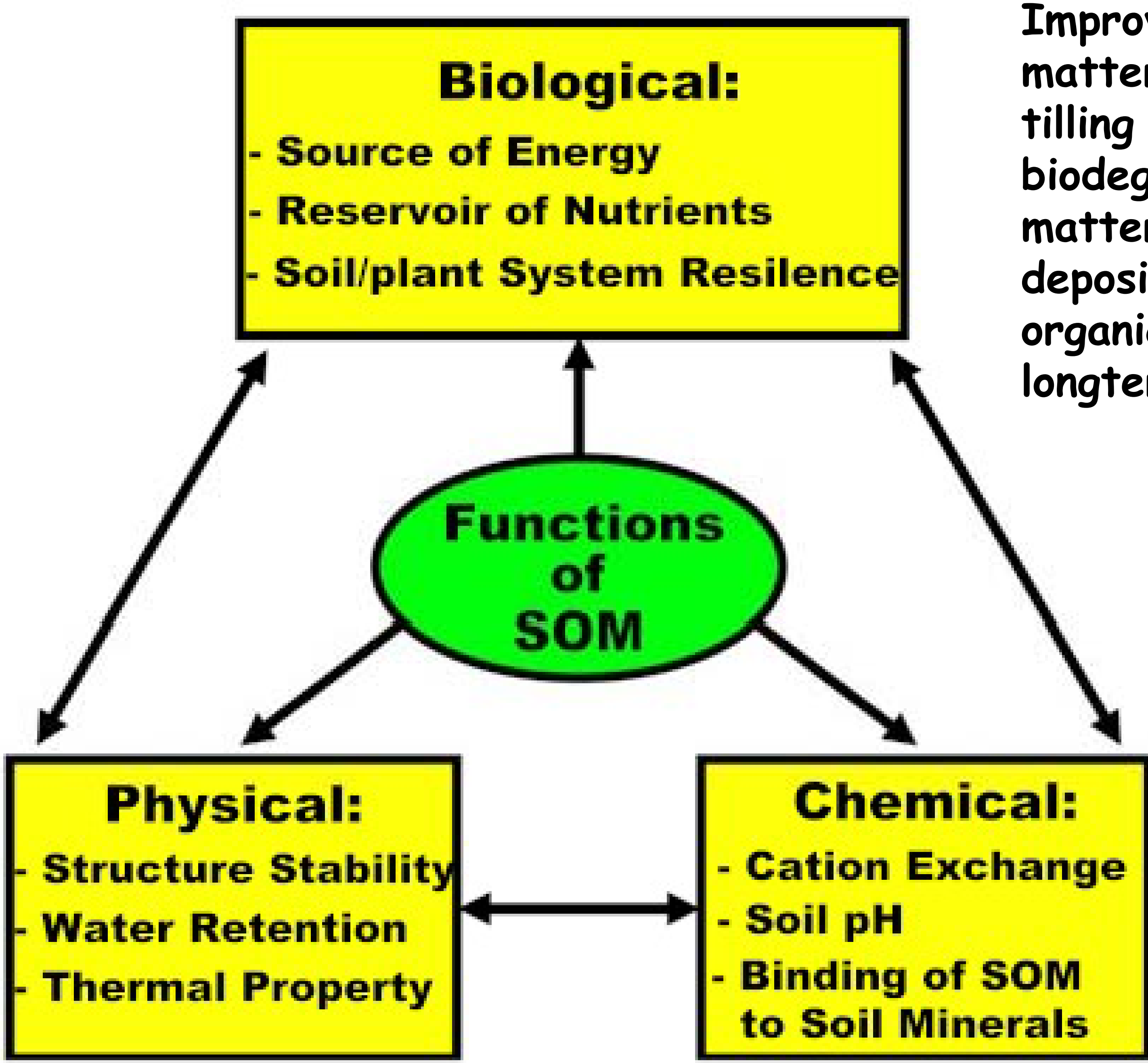
    - Ideal: 1.4
    - Acceptable: 1.2 – 1.6
  - Soil texture
    - Match plants with soil texture
  - **Organic matter**
    - **Ideal: > 3%**
    - **Acceptable: > 2%**
  - pH
    - Ideal: 6.5 - 7.5
    - Acceptable: 5.5 – 8.5

Organic rich top soil


Soil Organic Matter Extraction Test
LOW
1.0-1.5 %
MEDIUM
2.0-2.5 %
HIGH
3.0-3.5% *
*(or higher)



Improve soil organic matter content by tilling in compost and biodegradable organic matter; rebuilding deposits of stable organic matter is a longterm process.

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  - **pH**
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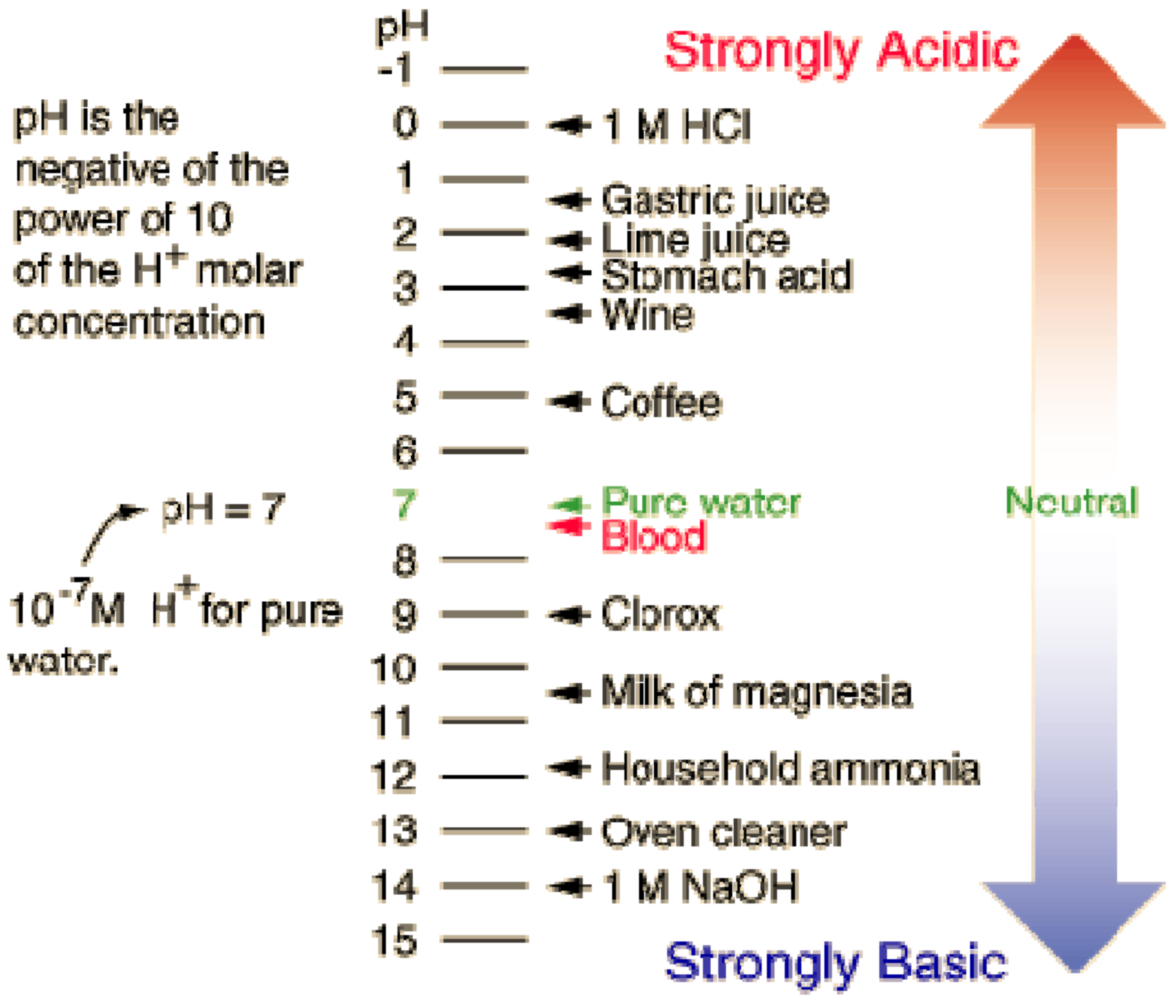
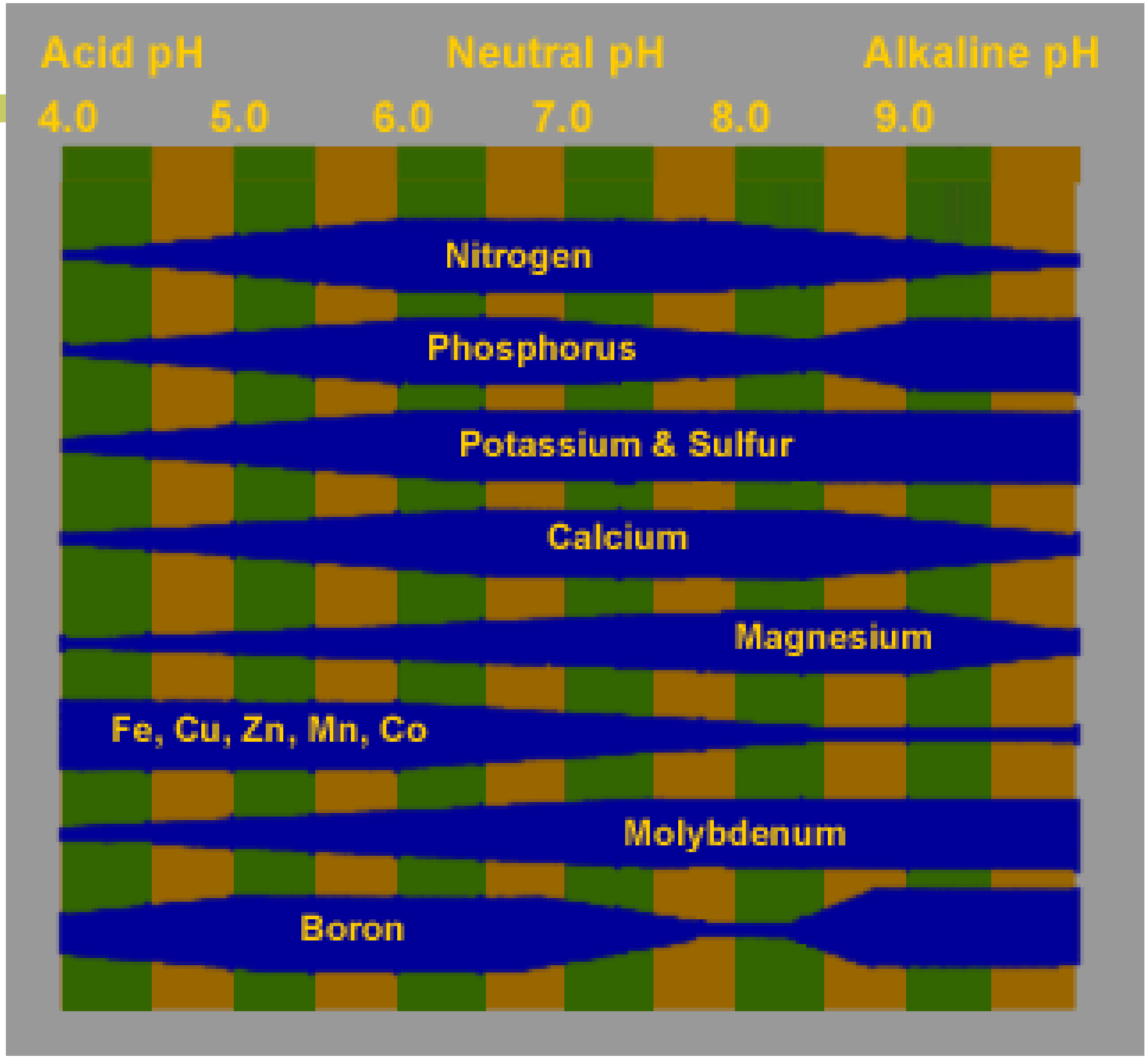
    - **Match plants with soil pH**

pH



pH
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Strongly Acidic
1 M HCl
Gastric juice
Lime juice
Stomach acid
Wine
Coffee
Pure water
Blood
Neutral
Clorox
Milk of magnesia
Household ammonia
Oven cleaner
1 M NaOH
Strongly Basic
pH is the negative of the power of 10 of the H+ molar concentration
pH = 7
10-7M H+ for pure water.

pH affects nutrient availability



Reference

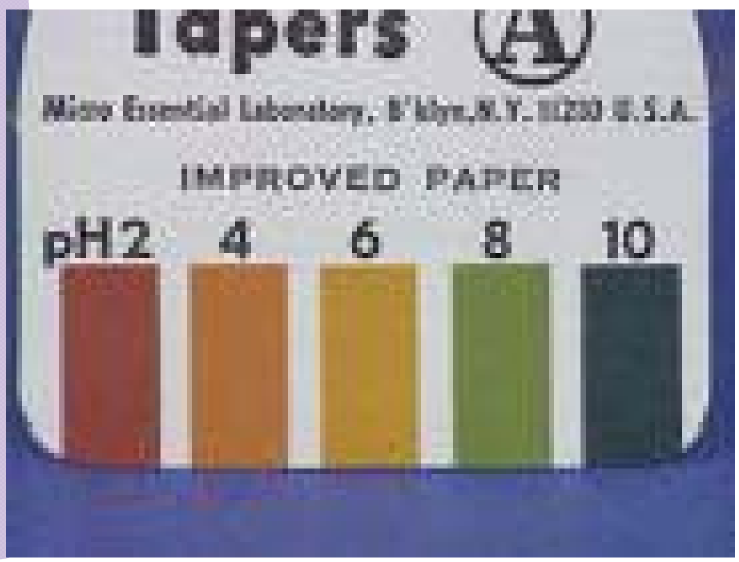
Measuring soil pH

- In a clean cup mix approximately equal volumes of soil and water
  - Distilled or deionized water from the grocery store or, better yet, use rain water
- Stir for about 30 sec, wait a few minutes and then repeat; finally allow the soil to settle
- Measure the pH of the water layer (it's OK if it's cloudy) using a pH meter, pH paper, or field kit

Reference

pH paper

pH paper contains dyes that are different colors at different pH values



Reference

Soil pH field test kit

Sold in lawn and garden supply stores; same basic method as pH paper

Reference

pH meter

Buffers to standardize meter

Adjusting pH

- Neutralizing acidity (to raise pH):
  - Ag lime- dolomite or calcitic limestone crushed and ground to a specified fineness
    - Calcitic limestone – crystalline calcium carbonate ($CaCO_3$)
    - Dolomite – mixture of calcium carbonate and magnesium carbonate

Adjusting pH, cont.

- Increasing acidity (to lower pH):
  - Elemental sulfur
  - Aluminum sulfate [$Al_2(SO_4)_3$]
  - Ferrous sulfate ($FeSO_4$)

Get help from your local ag lab

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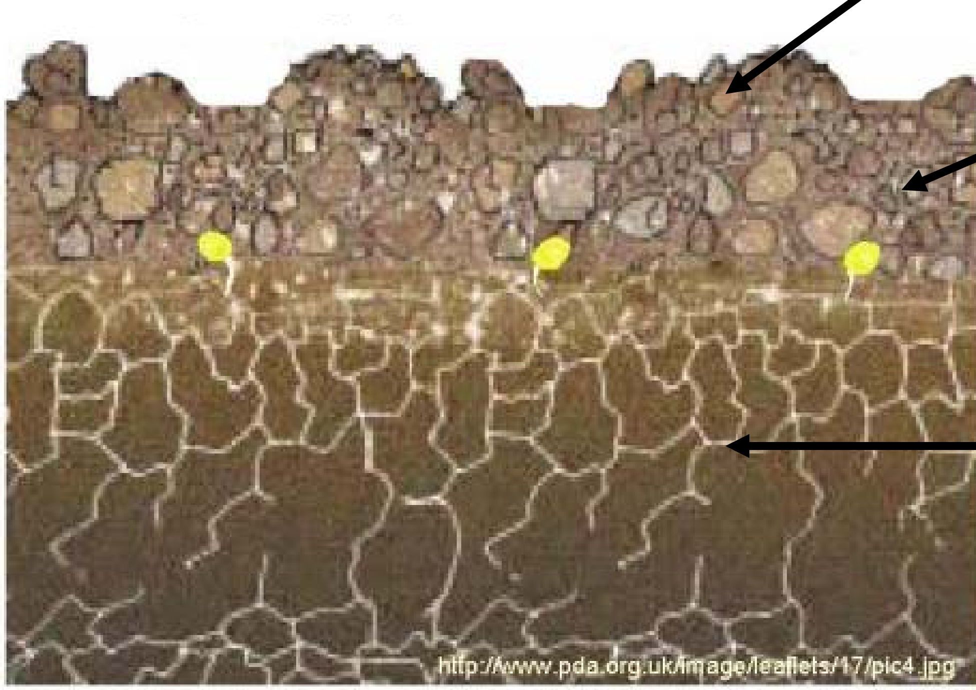
Note: It is usually better to use species adapted to site pH instead of altering pH – especially if the surrounding area has similar pH

Reseeding a remediated site, replacement soil, or other restoration site

- Seedbed preparation



Organic matter to retain moisture

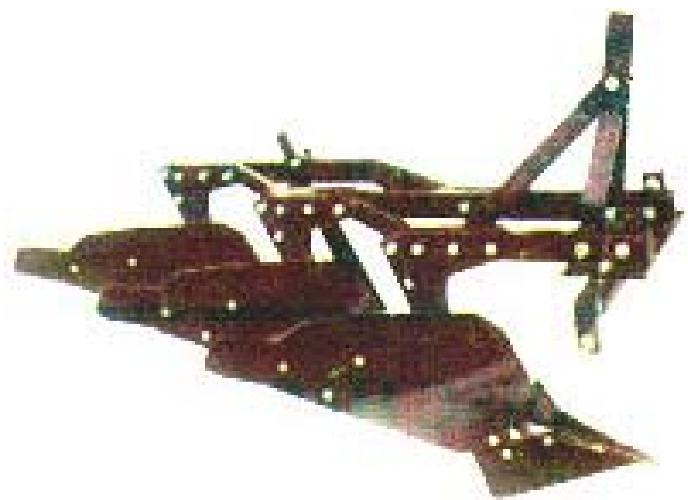
Soil loose enough to allow emergence; shallow enough to allow seedling to emerge before running out of energy

Soil sufficiently firm to provide a stable foundation for roots but porous enough to allow for good root penetration

Seedbed preparation

- Primary tillage
  - Most aggressive tillage
  - Cuts and shatters soil
  - Buries applied organic matter
  - Leaves rough surface
- Secondary tillage
  - Follows primary tillage
  - Normally shallower working depth
  - Provide additional soil pulverization
  - Large clods may result in seeds being buried too deep
  - Level soil surface
  - Control weeds

Primary tillage implements

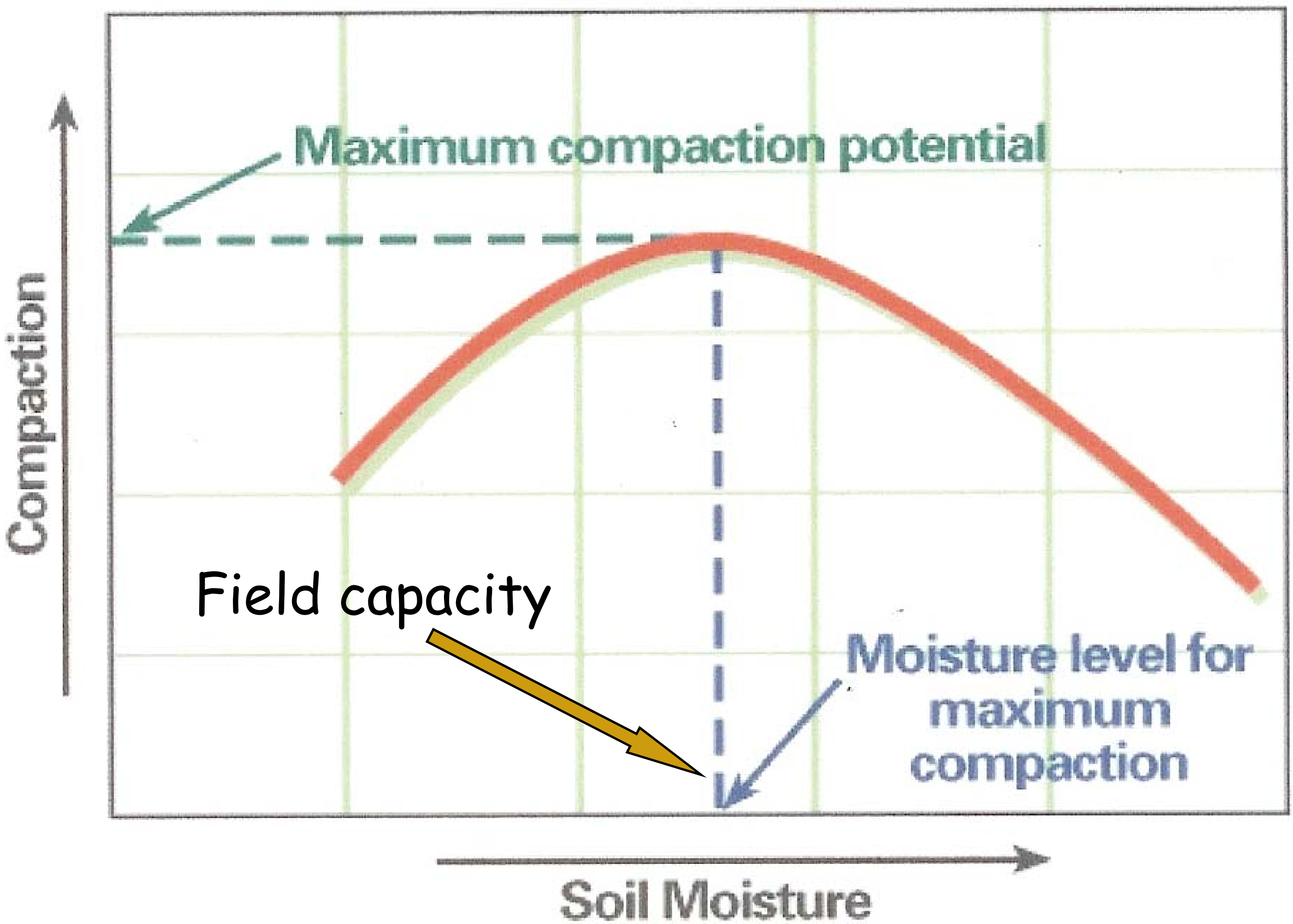


Field after primary tillage

Secondary tillage

Field after secondary tillage

Avoid excessive soil compaction while preparing the seedbed

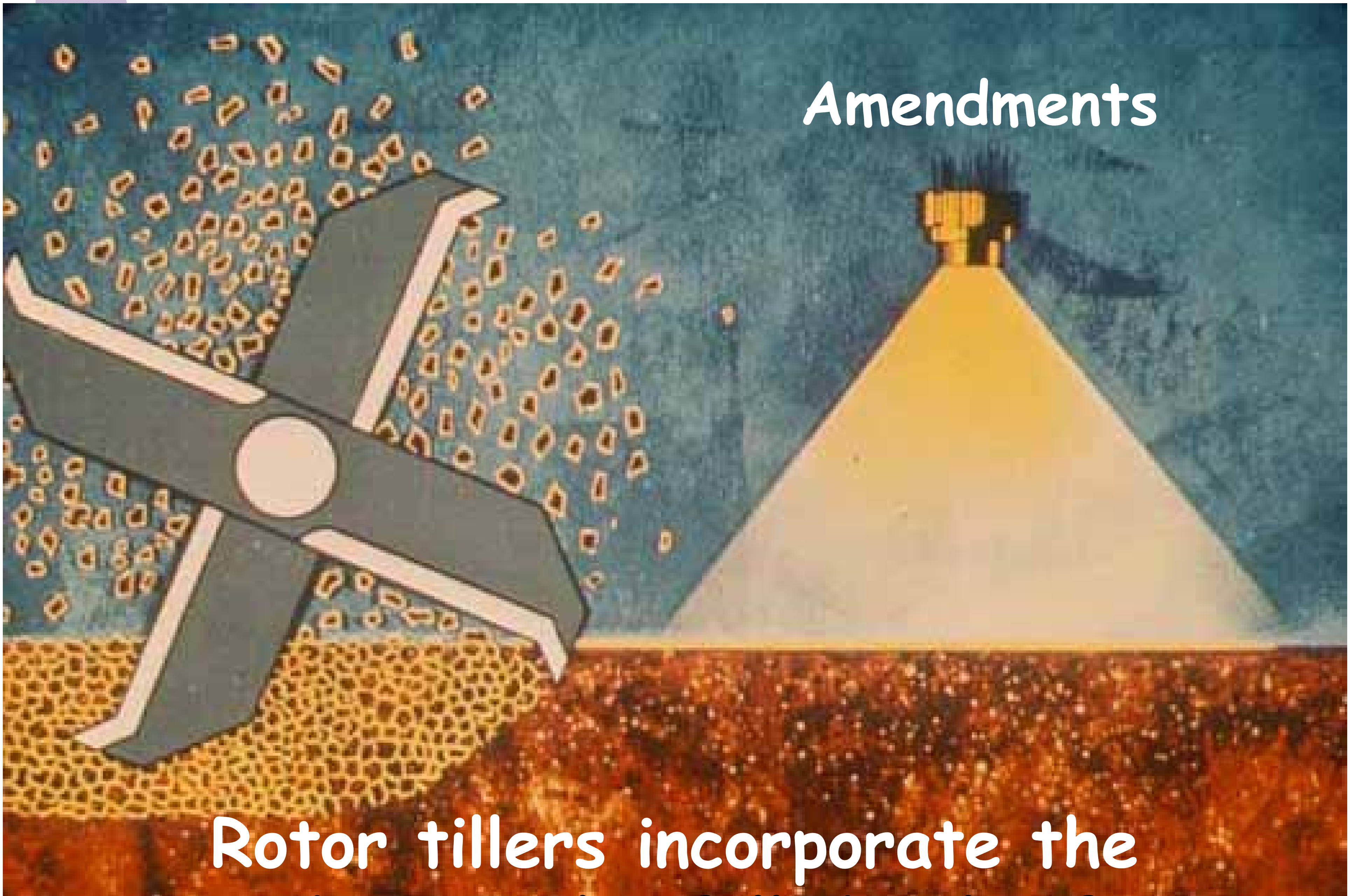


Seedbed preparation, cont.

- During secondary tillage incorporate any necessary soil amendments
  - Topsoil, if needed
  - Organic matter
    - In arid and semiarid areas use compost supplemented with hydrogels – captures and holds water
      - Recommended by USDA Dept. of Agricultural Research

RestorNhance™

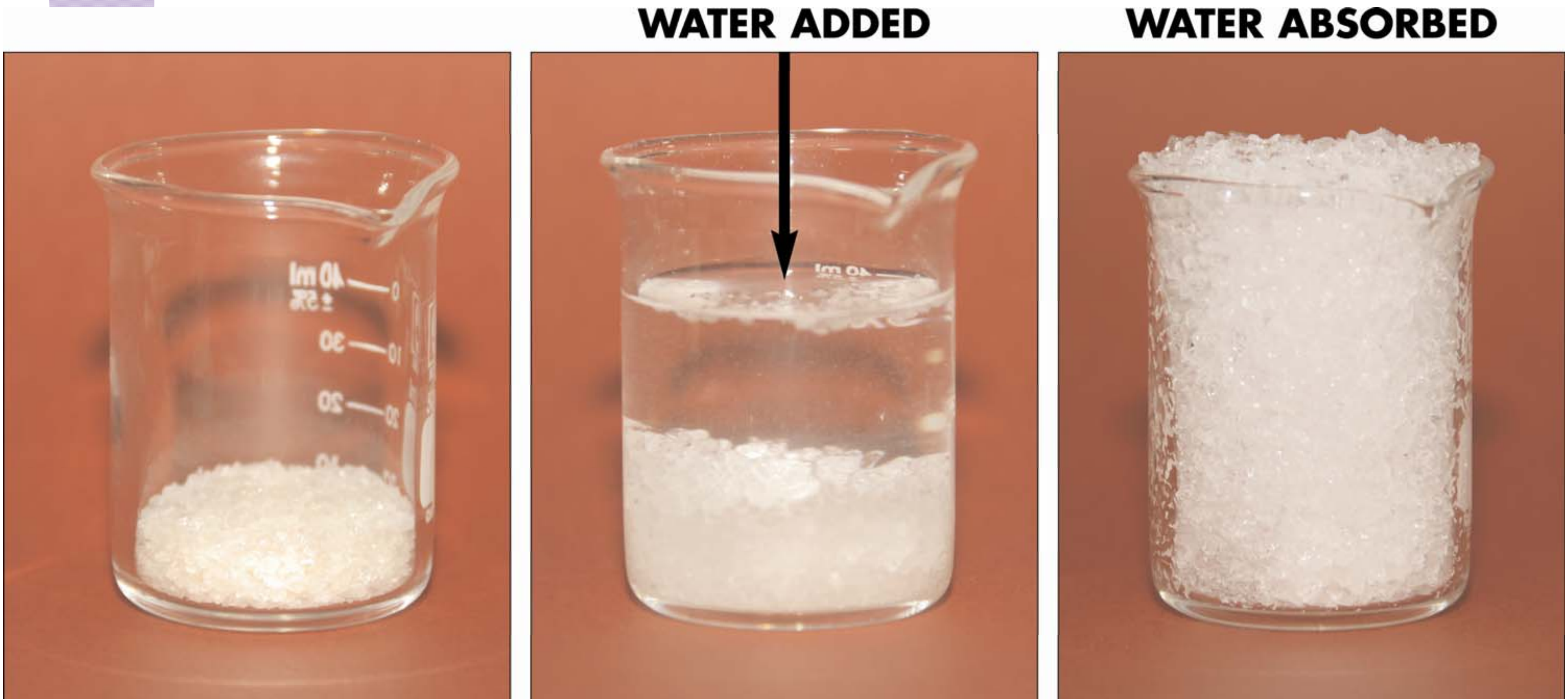
  - Fertilizers

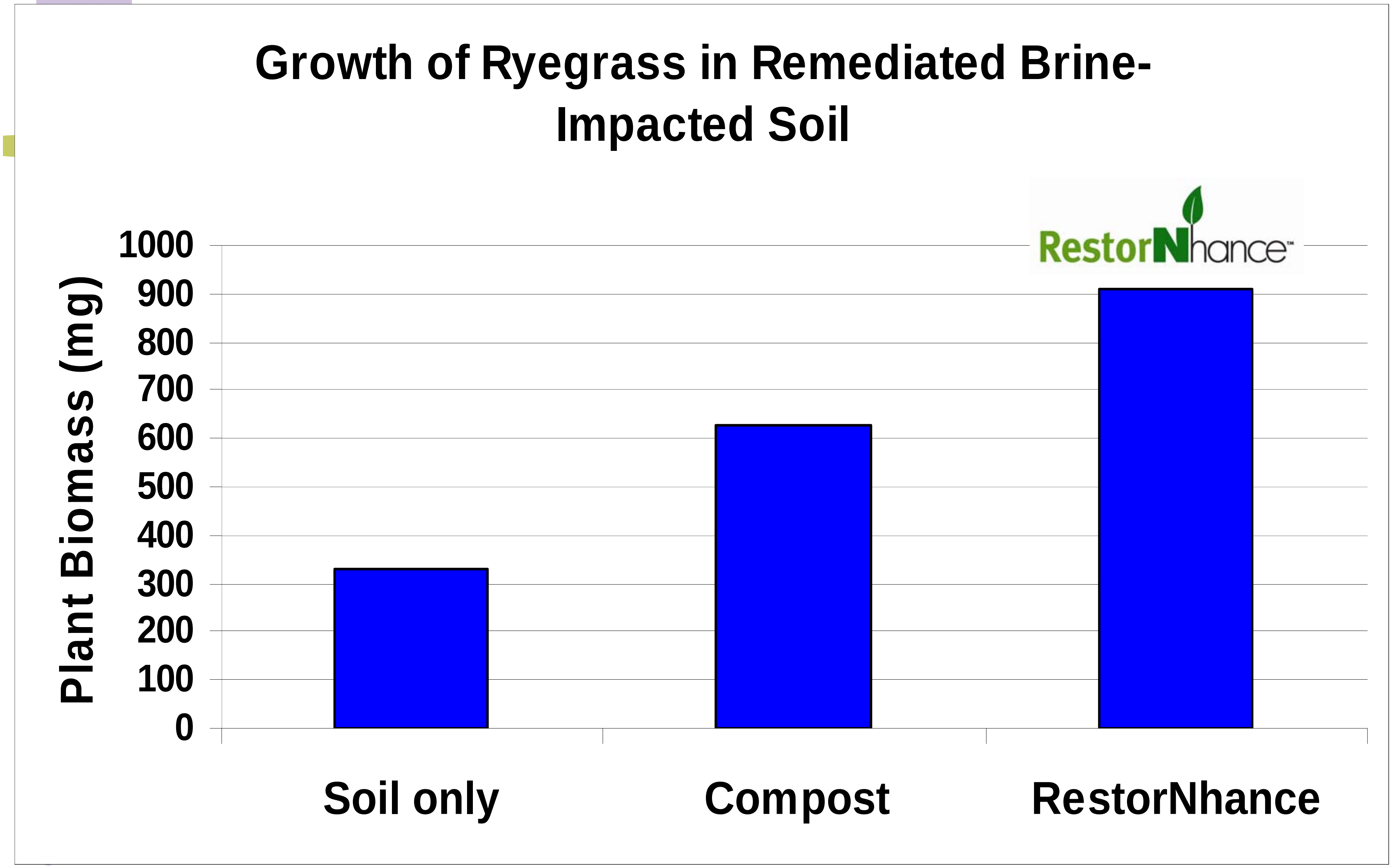


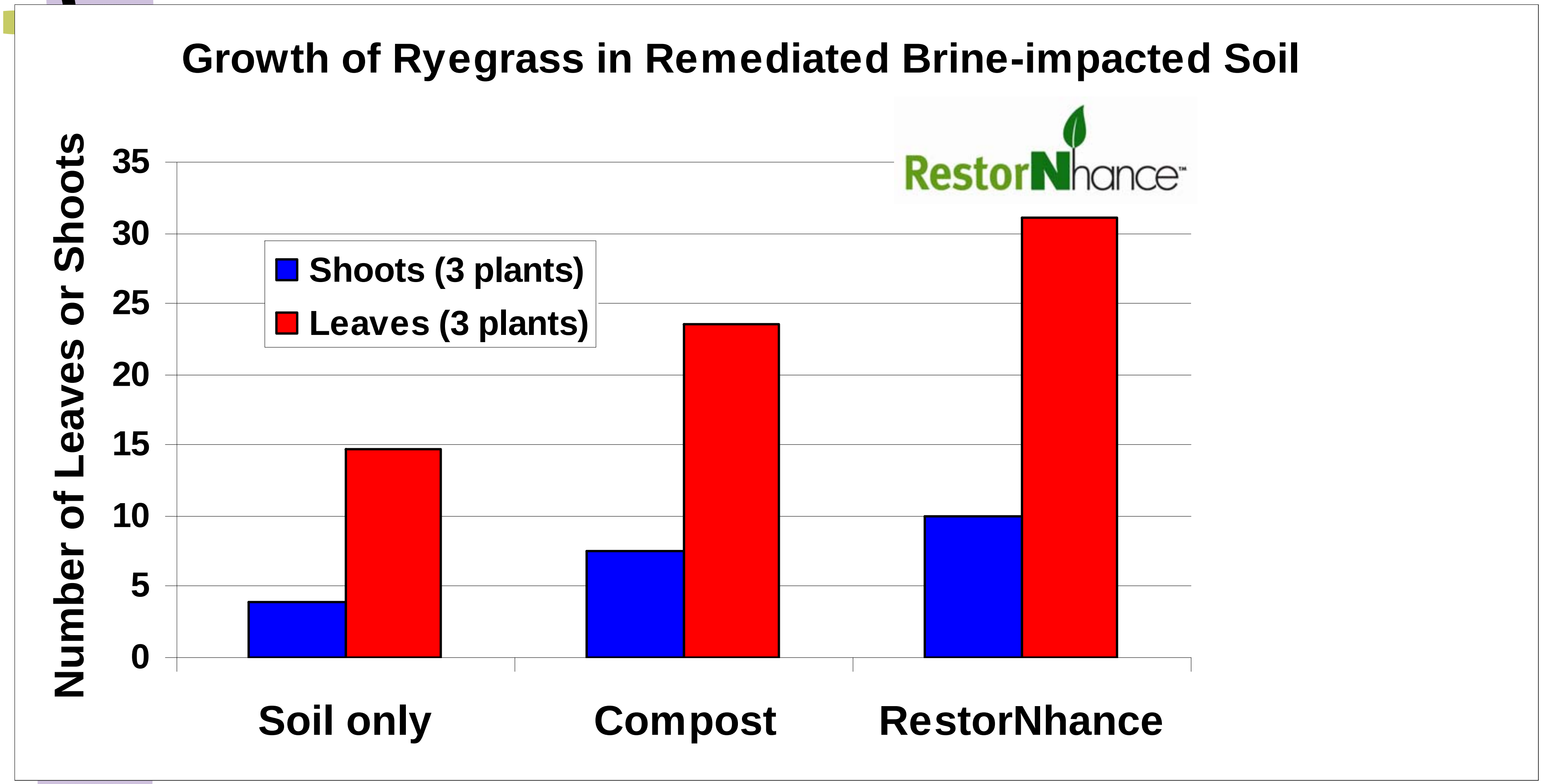
Rotor tillers incorporate the amendments the full depth of cut


An activating rainfall is needed
with most soil amendments

The power of hydrogels



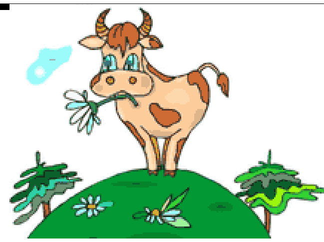

Growth of Ryegrass in Remediated Brine-Impacted Soil
RestorNhance
Plant Biomass (mg)
1000
900
800
700
600
500
400
300
200
100
0
Soil only
Compost
RestorNhance


Growth of Ryegrass in Remediated Brine-impacted Soil
RestorNhance
Number of Leaves or Shoots
35
30
25
20
15
10
5
0
Shoots (3 plants)
Leaves (3 plants)
Soil only
Compost
RestorNhance

Fresh Cow Manure	Composted Cow Manure[4]
Wet with strong odor	Earthy smell[1] Moist-dry
High nutrient concentrations	Low nutrient concentrations 1-3% N, 0.5-1% P_2O_5, 1-2% K_2O (Releases about 10% of its nutrients per year)
High tendency to "burn"[2]	No burning, safe fertilizer
High salinity	Usually much lower salinity[3]
Weed seeds and pathogens	Weed seeds and pathogens killed by composting
Biodegradation in soil tends to deplete oxygen	No negative effect on soil gas oxygen

[1]If it smells of ammonia its not done yet.

[2]Must let fresh manure age 60-90 days to prevent burning.



[3]Check salinity before use. Make a paste with distilled water and measure EC. If EC < 10 mmhos/cm it's OK to use if you till it in 6-8 inches.

[4]Density 15-25 lbs/ft^3 or 400-675 lbs/yd^3 dry; X 2 moist

Seedbed preparation, cont.

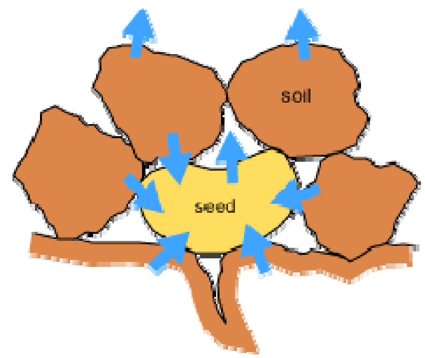
- After secondary tillage light packing of the soil provides a firm but penetrable seedbed

Seedbed too soft

Is this seedbed too soft?

Seedbed preparation, cont.

- Roughing the surface before seeding creates safe sites for seeds and collect moisture
- Light chaining after broadcasting seeding facilitates good contact of the seed with soil
- Overlay with a thin layer of soil/compost/hydrogel product like RestorNhance™

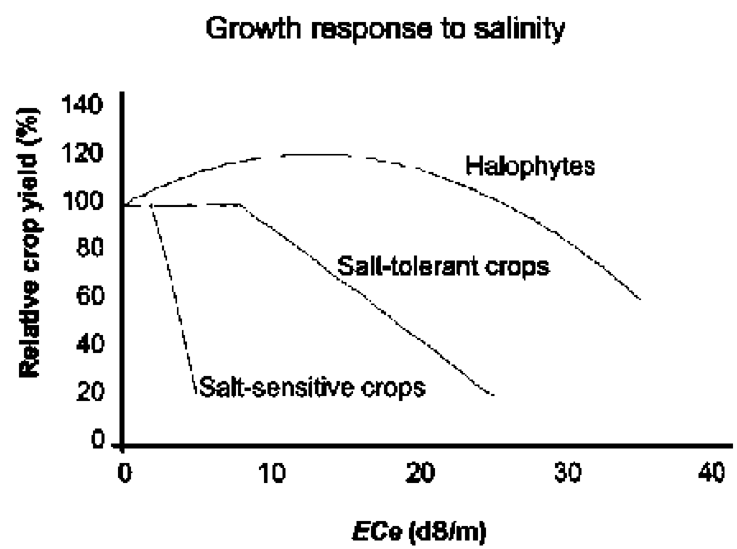


Seedbed preparation, cont.

- In areas that are very hot and windy plant a stubble crop the year before seeding with the desired vegetation (use a sterile annual cool season grass)
- The next season rough the surface by light raking, sow seeds and pack lightly
- Stubble crop provides shade and wind protection for new seedlings

What to seed?

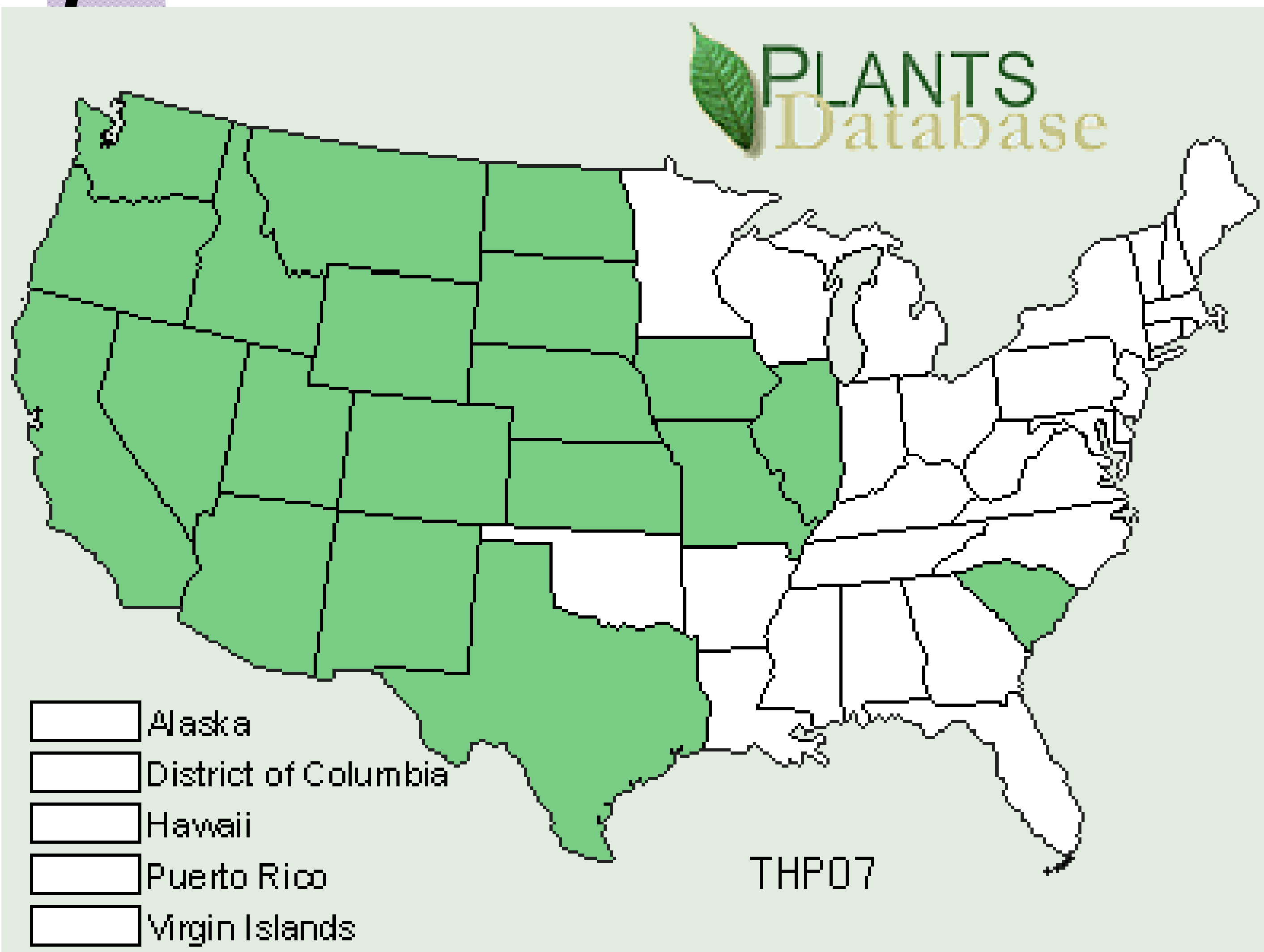
- Depends on management objectives
  - Forage crops
  - Native vegetation
  - Quick growing species for erosion control
  - Halophytes
    - Get advice from local soil conservation district office about species native to your area



Regardless of objective

- Choose plants that are adapted to soil, climate, elevation, and topography of the area top be restored
- Important to know origin of seeds
- Seeds should originate from sources from within 200 miles N and S and 100 miles E and W
- Use certified named varieties
- Mixtures are preferred over single species
  - Especially different rooting depths
  - Most efficient use of moisture and nutrients
- Use seed of known quality
- Know germination and purity of seed
- Published seeding rates are based on pure live seeds (PLS)
  - %PLS = % purity X % germination

Go to http://plants.usda.gov to get plant distributions by state



This one is for tall wheatgrass. In the web site you click on a state and you get the distribution of the plant by county in that state.

In the appendix

Table 1 – part 1 - Seed characteristics, seeding rates and adaptations of species used for seeding Texas rangeland

				Ratings of adaptation[3]							
				Tolerance			Soil				
Name	Variety[1]	Seeds per lb.	Broadcast Seeding rate[2] (lb PLS per acre)	Drought	Cold	Salt	Sandy	Loam	Clay	Native (N) or Introduced (I)	Season of Growth[4]
Alkali sacaton (*Sporobolus airoides*)		1,750,000	1.0	2	1	1	3	2	1	N	W
	Saltalk			2	1	1	3	2	1	N	W
	Salado			1	1	1	3	2	1	N	W
Angelton bluestem (*Dichantium aristatum*)		500,000	1.0	2	3	2	3	3	1	I	W
Big bluestem[7] (*Andropogon gerardii*)		130,000	6.0	2	1	2	2	1	2	N	W
Black grama (*Bouteloua eriopoda*)	Nogal	1,335,000	1.5	1	2	3	1	1	3	N	W
Blue grama		711,000	1.5	1	1	2	2	1	1	N	W
(*Bouteloua gracilis*)	Lovington	(spikelet)		1	1	2	2	1	1	N	W
	Hachita			1	1	2	2	1	1	N	W

In the appendix

Table 1 – part 2 – Adaptations of species used for seeding Texas rangeland

		Regional Adaptations[5]																		6
Name	Variety[1]	Coast Saline Prairie	Coast Prairie	East Texas Timberlands	Claypan Area	Blackland Prairie	East Cross Timbers	West Cross Timbers	Grand Prairie	North Central Prairie	Central Basin	Edwards Plateau	Northern Rio Grande	Western Rio Grande Plains	Central Rio Grande Plain	Lower Rio Grande Valley	Rolling Plains	High Plains	Trans-Pecos	Minimum Rainfall (inches)
Alkali sacaton (*Sporobolus airoides*)												X	X	X	X	X	X	X	X	10
	Saltalk				X		X	X		X							X	X		10
	Salado												X	X	X	X			X	10
																				30
Angelton bluestem			X																	
(*Dichantium aristatum*)																				
Big bluestem[7]		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	25
(*Andropogon gerardii*)																				
Black grama	Nogal																	X	X	10
(*Bouteloua eriopoda*)																				

In the appendix

Table 1. Selected species for revegetation projects.

Name	Cultivar	Preferred Soil Type	Minimum Ppt. (inches)	Pure Stand PSL Rate/Acre (pounds)	Notes
Native bunchgrasses–short to medium					
Indian ricegrass (*Achnatherum hymenoides*)	Nezpar, Paloma, Rimrock	sandy to loamy	8	12	Drought tolerant. Easy to moderate establishment, relatively short-lived. Useful in coarse soils on low-fertility sites. Highly palatable and nutritious.
Idaho fescue (*Festuca idahoensis*)	Joseph	silty-loamy to clayey	10-12	8	Moderately drought tolerant. Slow establishment. Poor seedling vigor. Good palatability.
Squirreltail (*Elymus elymoides*)	Sand Hollow	sandy to loamy	6	12	Short-lived. Fair seedling vigor. Becomes unpalatable at maturity. Often seeded as a mid-successional species. Competitive with cheatgrass and medusahead.
Sandberg's bluegrass (*Poa sandbergii*)	High Plains	sandy to clayey	8	4	Very drought tolerant. Slow establishment. Can withstand considerable grazing pressure.
Native bunchgrasses–medium to tall					
Mountain brome (*Bromus carinatus*)	Bromar	silty-loamy to clayey	12-16	15	Rapid establishment. Short-lived. Adapted to relatively moist soils. Good livestock forage value.
Tufted hairgrass (*Deschampsia caespitosa*)	Nortran	silty-loamy to clayey	20 (riparian)	2	Long-lived. Most common in moist sites and at higher elevations. Very palatable to livestock and wildlife.
Native bunchgrasses–medium to tall					
Canada wildrye (*Elymus canadensis*)		sandy	12	15	Rapid establishment. Short-lived. Prefers moist or periodically moist, well-drained sites. Good palatability, but poor grazing tolerance.
Prairie Junegrass (*Koeleria cristata*)		sandy	12	2	Drought tolerant. Easy establishment. Good-quality early spring forage.
Sand dropseed (*Sporobolus cryptandrus*)		sandy	10	2	Extremely drought tolerant. Moderate palatability. Prolific seed producer, tends to increase on poor condition rangelands. Seed should be scarified before planting.

When to seed?

- Try to seed just before season of expected high rainfall
- Cool season grasses may be planted in spring or early fall (ideally in the fall)
- Warm season grasses in spring

When to seed?

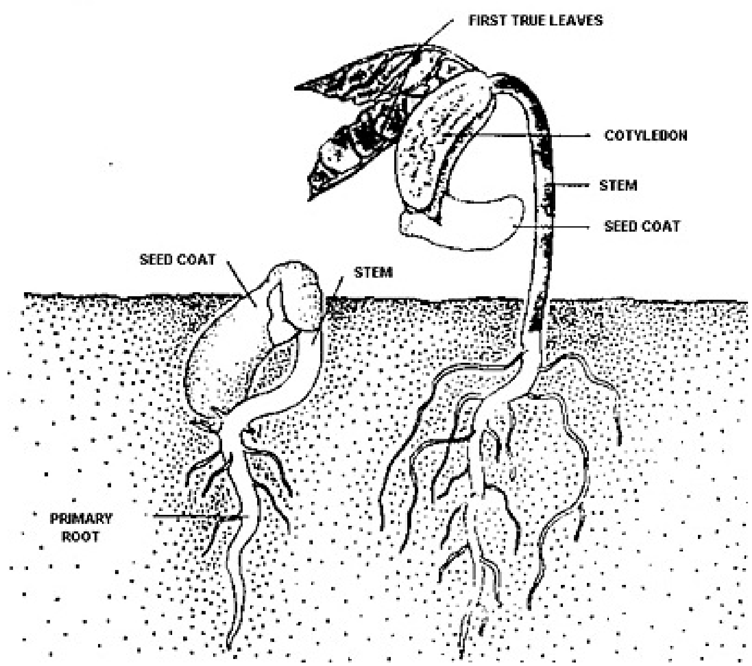
- If you are planning a spring planting, begin seedbed preparation in the fall prior to planting the following spring.
- Preparation of the site in the fall will damage the root systems of perennial weeds and expose them to freezing temperatures and the dehydrating action of winter winds.
- In the following spring, the ground should be worked at a shallow depth (secondary tillage) at least twice to break up clods and eliminate annual weeds.

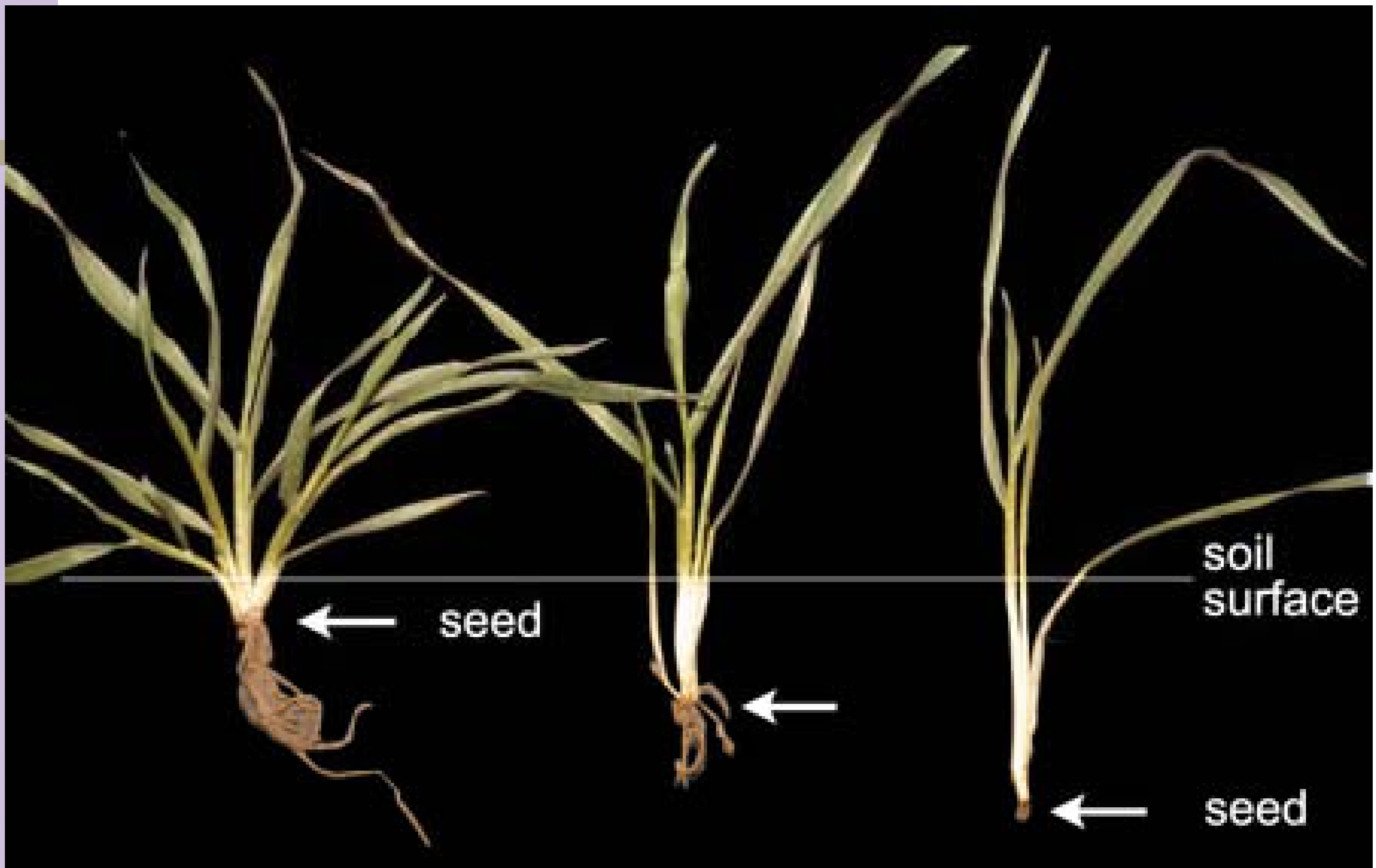
How to seed?

- Broadcast seeding must be done on loose, roughened soil, seeding is followed by chaining
- Seeding rates are typically 20-50 seeds/ft^2

How to seed?

- Depth
  - Seeds have stored energy, sprout must break the surface and produce leaves before getting energy from the sun. If the seed is planted too deep the sprout can't make it to the surface
  - General rule of thumb – plant seeds at a depth 4-7 X the diameter of the seed
  - With a mixture base planting depth on the diameter of the smallest seed
  - Avg $\frac{1}{4}$ - $\frac{1}{2}$ inch




seed
soil
surface
seed

Common causes of planting and emergence problems

- Insufficient moisture
- Seedbed too hard or too loose
- Old seeds, dead before planting or had low vigor.
- Too few seeds were planted.
- Seeds were planted too deep.
- Seeds were not uniformly distributed
- Seeds were planted too shallow and dug up by birds or moved by insects.
- Sowing occurred too long after cultivation allowing weeds to establish and compete with crop seedlings for resources.
- Heavy rain fell after sowing and the soil surface crusted.

Management of revegetation sites

- If natural precipitation is inadequate – must water to establish seedlings!
- Water only until plants are established, if well matched to the local climate they will persist with normal rainfall
- Watch for drought stress during this period of establishment, monitor soil moisture
- Protect the site from compaction by livestock
- Monitor for signs of nutrient deficiencies in plants

Management of revegetation sites

- Light mulch
  - Protects seeds from wind and water erosion, conserves moisture, moderates soil temperature
  - Use local hay, weed free
  - Tackifiers help in windy climates (guar gum, polyacrylamides)
- Protect from grazing until roots have firmly established (usually 2-3 years)
- Watch for signs of foraging by wildlife
- Hand pull weeds or spot herbicide
  - Most grass seedlings can tolerate herbicide application after reaching the 4 leaf stage

Management of revegetation sites

- Watch for
  - Foraging by wildlife
  - Erosion
  - Areas of revegetation failure
- **Nutrient management is especially important when gypsum has been used in remediation of brine spills!**

Poorly prepared fields will cause management problems in revegetation

Symptoms include:

- Poor plant establishment
- Excessive pest / weed burdens
- Uneven plant growth and maturity
- Poor water use efficiency

→ **"You reap what you sow"**

Recent revegetation project

Applying fertilizer, organic matter and hydrogels

Recent revegetation project

Incorporating amendments during secondary tillage in amendments

Recent revegetation project

Firming the seedbed

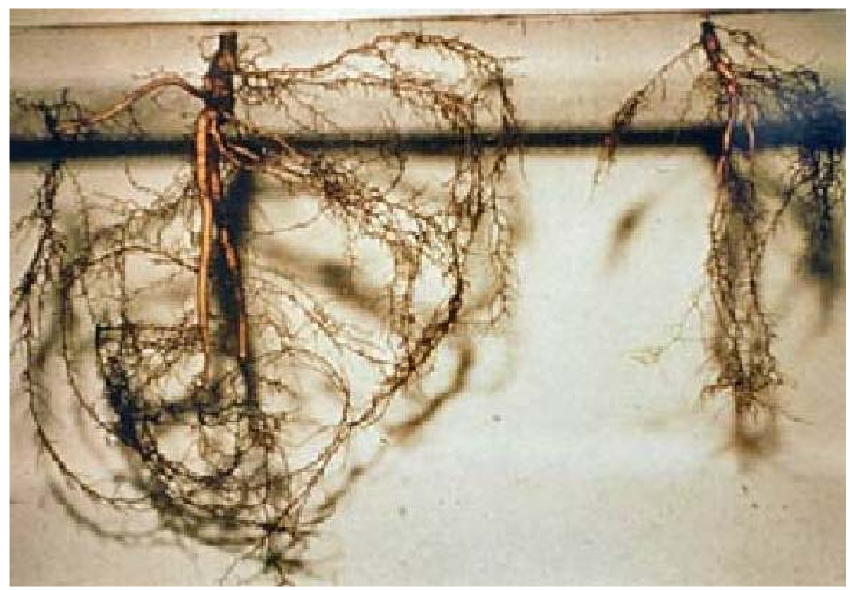
Recent revegetation project

Establishing good seed-soil contact following seeding with sudan grass (June)


4 weeks later

Mycorrhizal fungi and plant available P

- Soil P will typically move only about 0.1 in, so plant roots must continually grow into new areas to get P
- Mycorrhizal fungi act as extension of plant roots to increase P uptake -fungi get sugars from plants

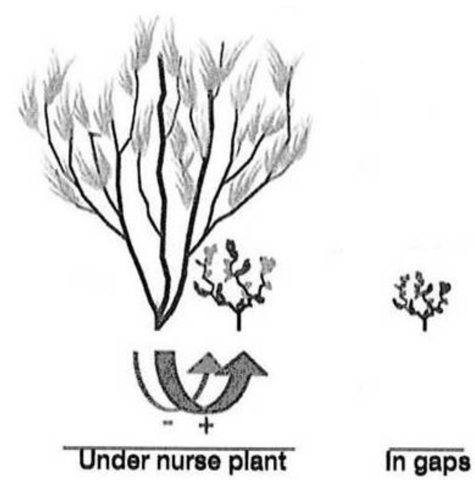


Introducing mycorrhizal fungi

- Inocula of mycorrhizal fungi are available commercially. As your county ag extension service if the vegetation you desire can benefit from mycorrhizal fungi.
- Collect top litter from surrounding weed-free landscape and work into top soil.
- A stubble crop also captures wind borne spores.

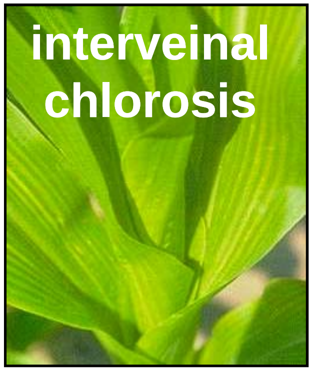
Nurse plants

- Shrubs as nurse plants (over story plants)
  - Increases water available by moisture interception
  - Enhance soil fertility
  - Reduce evaporation
  - Improves soil structure
  - Increases nutrient cycling
  - Adds organic matter from litter

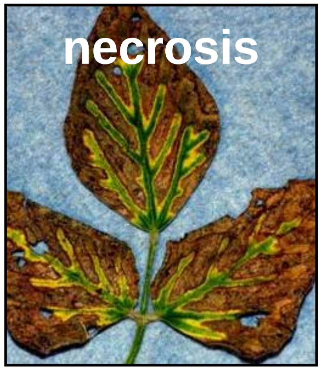


Terminology used to describe deficiency symptoms

Term	Definition
Chlorosis	Yellowing or lighter shade of green
Necrosis	Browning or dying of plant tissue
Interveinal	Between the leaf veins
Meristem	The growing point of a plant
Internode	Distance of the stem between the leaves
Mobile	A mobile element is one that is able to *translocate*, or move, from one part of the plant to another depending on its need. Mobile elements generally move from older (lower) plant parts to the plant's site of most active growth (*meristem*).



Michigan State University Extension



Delaware Coop. Extension

Element mobility and deficiency symptoms

Essential Element	Mobility	Deficiency Symptoms and Occurrence
Nitrogen  Iowa State Extension	Mobile within plants: lower leaves show chlorosis first.	▪Stunted, slow growing, chlorotic plants. ▪Reduced yield. ▪Plants more susceptible to weather stress and disease. ▪Some crops may mature earlier.
Phosphorus  Iowa State Extension	Mobile within plants: lower leaves show deficiency first.	▪Over-all stunted plant and a poorly developed root system. ▪Can cause purple or reddish color associated with the accumulation of sugars. ▪Difficult to detect in field.

Element mobility and deficiency symptoms

Essential Element	Mobility	Deficiency Symptoms and Occurrence
Potassium  Univ. of Minnesota Extension	Mobile within plants: lower leaves show deficiency first.	▪Commonly causes scorching or firing along leaf margins. ▪Deficient plants grow slowly, have poorly-developed root systems, weak stalks; lodging is common. ▪Seed and fruit are small and shriveled. ▪Plants possess low resistance to disease. ▪Deficiencies most common on acid sandy soils and soils that have received large applications of Ca and/or Mg.

Element mobility and deficiency symptoms

Essential Element	Mobility	Deficiency Symptoms and Occurrence
Calcium  Aarhus University	Not mobile within plants: upper leaves and the growing point show deficiency symptoms first.	▪Poor root growth: Ca deficient roots often turn black and rot. ▪Failure of terminal buds of shoots and apical tips of roots to develop, causing plant growth to cease. ▪Most often occurs on very acid soils where Ca levels are low. ▪Other deficiencies usually limit growth before Ca deficiency.
Magnesium  Clemson University	Mobile within plants: lower leaves show deficiency first.	▪Leaves show a yellowish, bronze or reddish color while leaf veins remain green.

Element mobility and deficiency symptoms

Essential Element	Mobility	Deficiency Symptoms and Occurrence
Sulfur  NC State Extension	Somewhat mobile within plants but upper leaves tend to show deficiency first.	▪Chlorosis of the longer leaves. ▪If deficiency is severe, entire plant can be chlorotic and stunted. ▪Symptoms resemble those of N deficiency; can lead to incorrect diagnoses.
Boron  North Central Regional Committee on Non-conventional Soil Additives	Not mobile within plants: upper leaves and the growing point show deficiency symptoms first.	▪Reduced leaf size and deformation of new leaves. ▪Interveinal chlorosis if deficiency is severe. ▪May cause distorted stems. ▪Related to flower and or fruit abortion, poor grain fill, and stunted growth. ▪May occur on very acid, sandy-textured soils or alkaline soils.

Element mobility and deficiency symptoms

Essential Element	Mobility	Deficiency Symptoms and Occurrence
Copper  Ontario Ministry of Agriculture, Food, and Rural Affairs	Not mobile within plants: upper leaves and the growing point show deficiency symptoms first.	▪Reduced leaf size. ▪Uniformly pale yellow leaves. ▪Leaves may lack turgor and may develop a bluish-green cast, become chlorotic and curl. ▪Flower production fails. ▪Organic soils are most likely to be Cu deficient.
Iron  North Central Regional Committee on Non-conventional Soil Additives	Not mobile within plants: upper leaves show deficiency symptoms first.	▪Interveinal chlorosis that progresses over the entire leaf. With severe deficiencies, leaves turn entirely white. ▪Contributing factors include imbalance with other metals, excessive soil P levels, high soil pH, wet, and cold soils.

Element mobility and deficiency symptoms

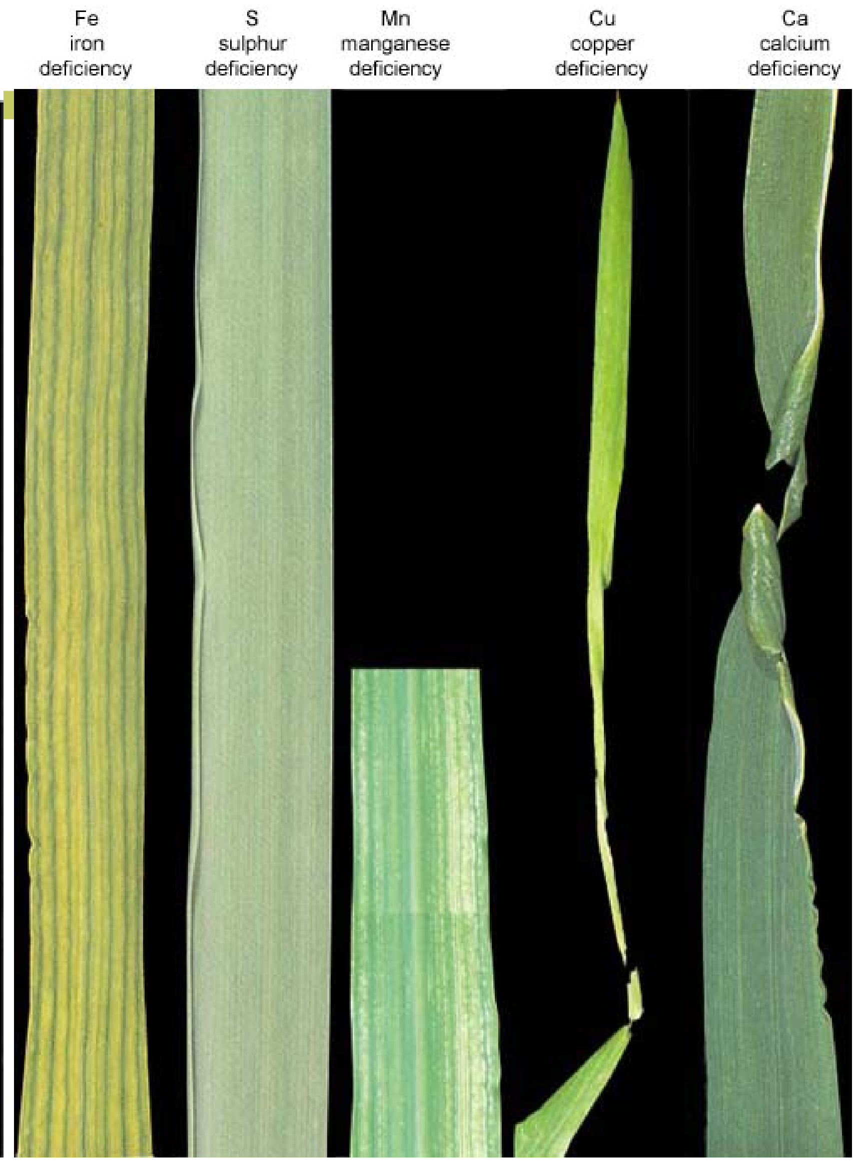
Essential Element	Mobility	Deficiency Symptoms and Occurrence
Manganese  Michigan State University Extension	Not mobile within plants: upper leaves show deficiency symptoms first.	▪Interveinal chlorosis. ▪Appearance of brownish-black specks. ▪Occurs most often on high organic matter soils and soils with neutral to alkaline pH with low native Mn content.
Zinc  University of Minnesota Extension	Not mobile within plants: upper leaves and the growing point show deficiency symptoms first.	▪Shortened internodes between new leaves. ▪Death of meristematic tissue. ▪Deformed new leaves. ▪Interveinal chlorosis. ▪Occurs most often on alkaline (high pH) soils or soils with high available P levels.

Element mobility and deficiency symptoms

Essential Element	Mobility	Deficiency Symptoms and Occurrence
Molybdenum	Not mobile within plants: upper leaves show deficiency symptoms first.	▪Interveinal chlorosis. ▪Wilting. ▪Marginal necrosis of upper leaves. ▪Occurs principally on very acid soils, since Mo becomes less available with low pH.
Chlorine	Mobile within plant, but deficiency symptoms usually appear on the upper leaves first.	▪Chlorosis in upper leaves. ▪Overall wilting of the plants. ▪Deficiencies may occur in well drained soils under high rainfall.
Cobalt	Used by symbiotic N-fixing bacteria in root nodules.	▪Causes N deficiency: chlorotic leaves and stunted plants. ▪Occurs in areas with soils deficient in native Co.
Nickel	Mobile within plants.	▪Symptoms and occurrence are not well documented.

Reference

N
nitrogen
deficiency
K
potassium
deficiency
P
phosphorus
deficiency
NaCl
salt
toxicity
Mg
magnesium
deficiency
Zn
zinc
deficiency



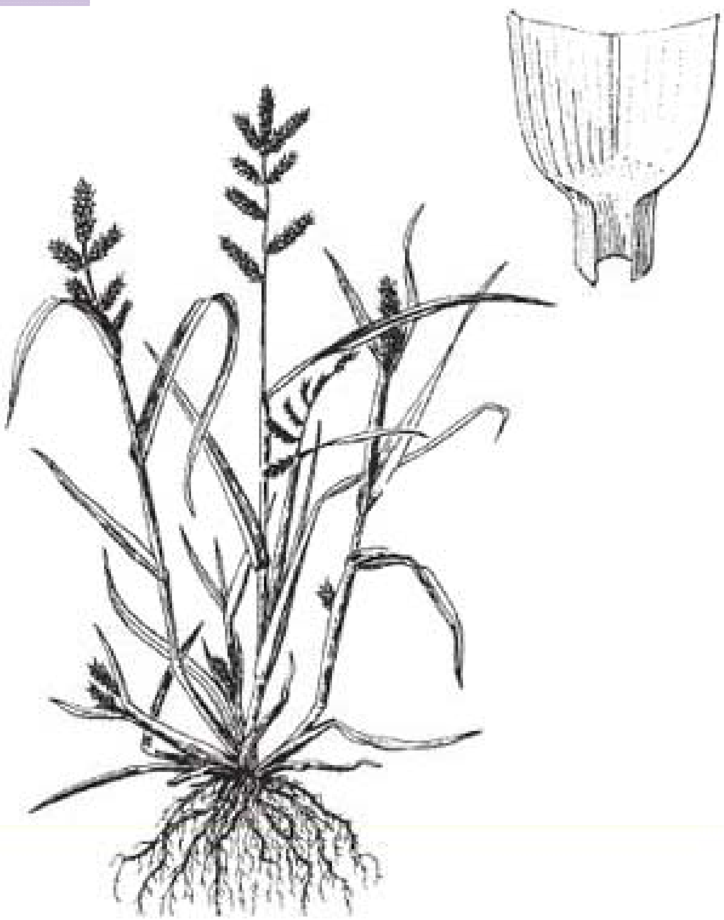
Fe
iron
deficiency
S
sulphur
deficiency
Mn
manganese
deficiency
Cu
copper
deficiency
Ca
calcium
deficiency

Weeds - biological indicators of the restoration of soil health and fertility

- During revegetation pay attention to the weeds that pop up
- The weeds that grow on your site can signal adverse growing conditions in the soil such as:
  - Too little water
  - Too much water
  - Low N
  - High N
  - Too much shade
  - Compaction
  - Low pH
  - General low fertility
- Send a cutting of the weed to your county extension office for identification and recommendations

Example

Barnyard grass-poor drainage

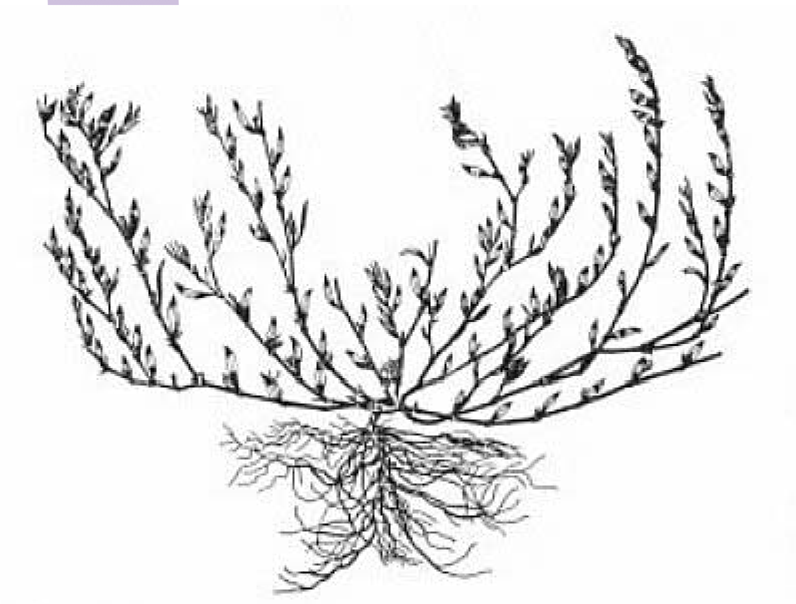


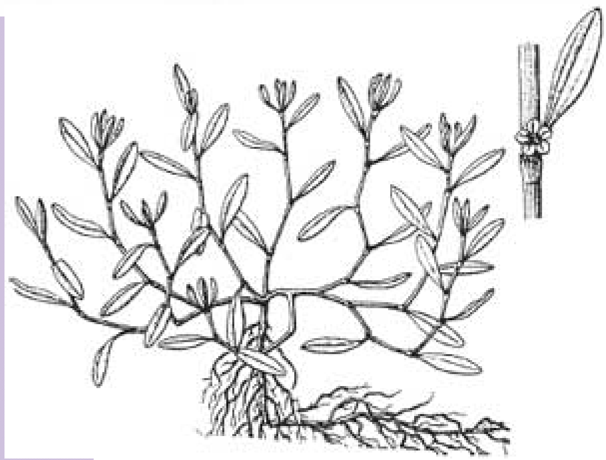
Example

Birdsfoot trefoil-drought, low nitrogen

Example

Prostrate knotweed-compaction

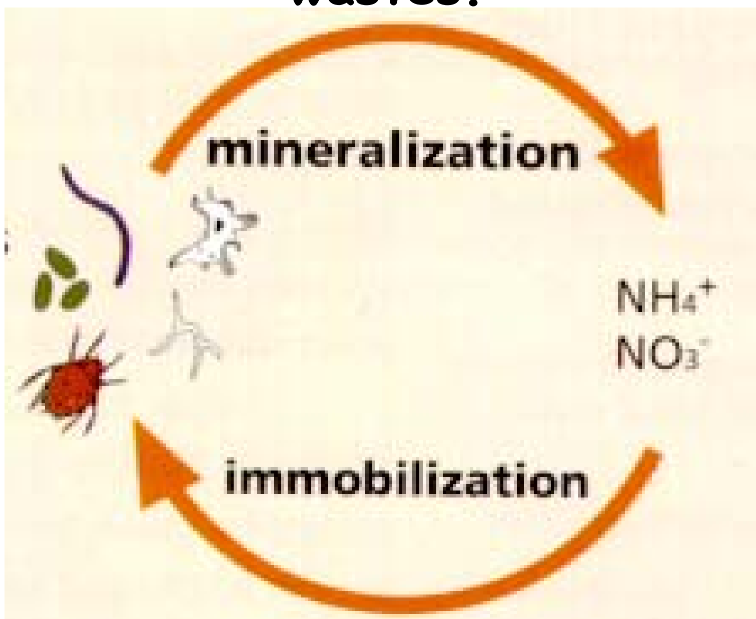




Monitoring overall soil health

Organisms consume other organisms and excrete inorganic wastes.

Organic nutrients are stored in soil organisms and organic matter.

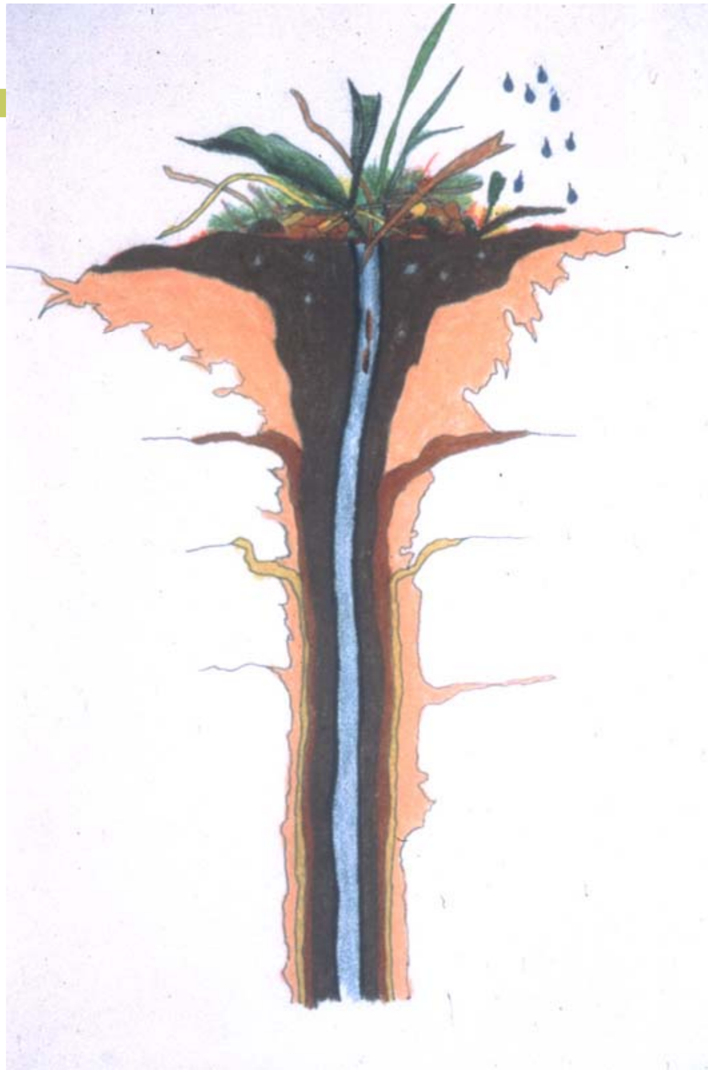


Inorganic nutrients are usable by plants, and are mobile in soil.

Organisms take up and retain nutrients as they grow.

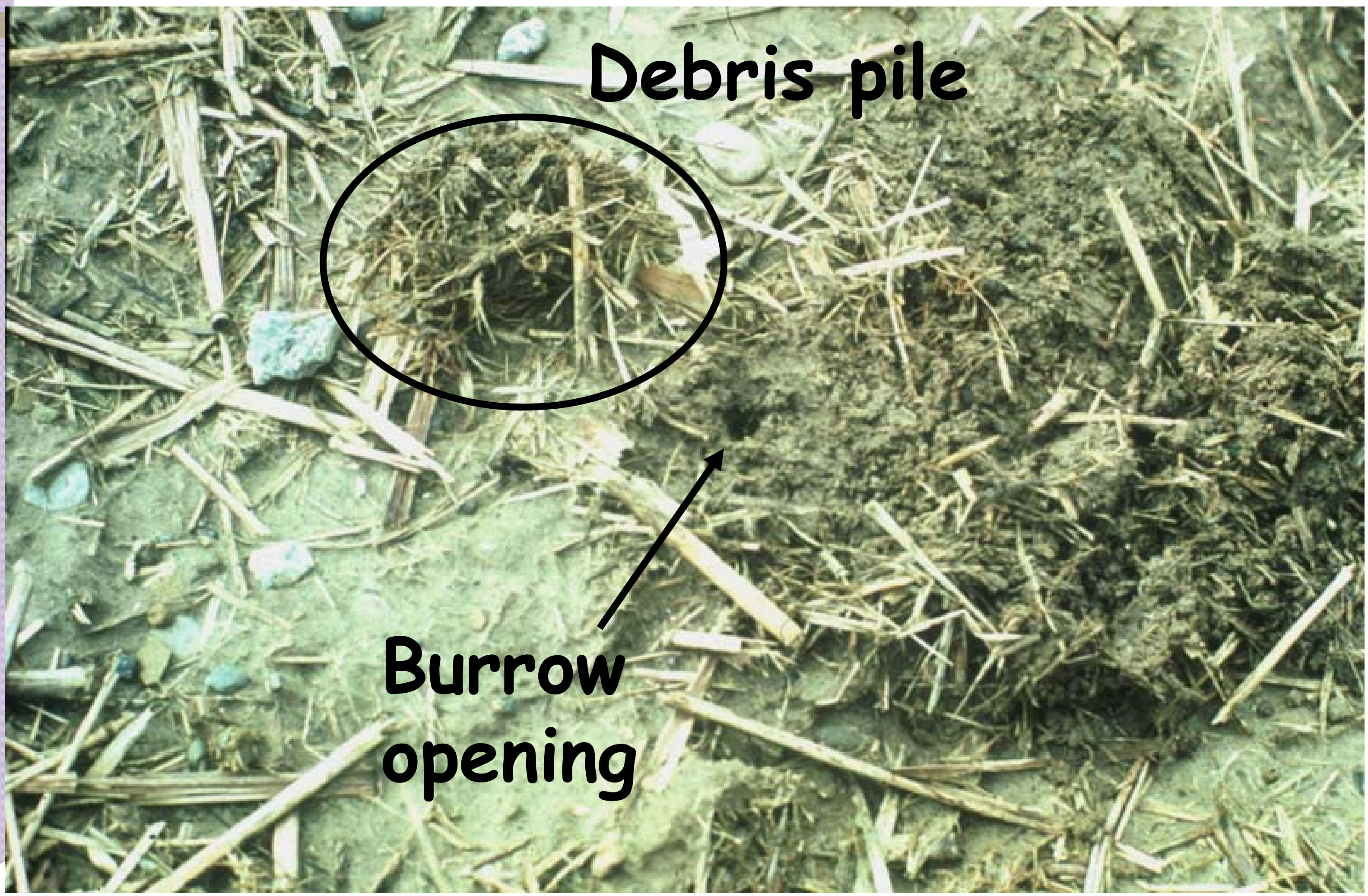
Earthworms as indicators and eco-engineers

Vertical burrows



Earthworm burrow

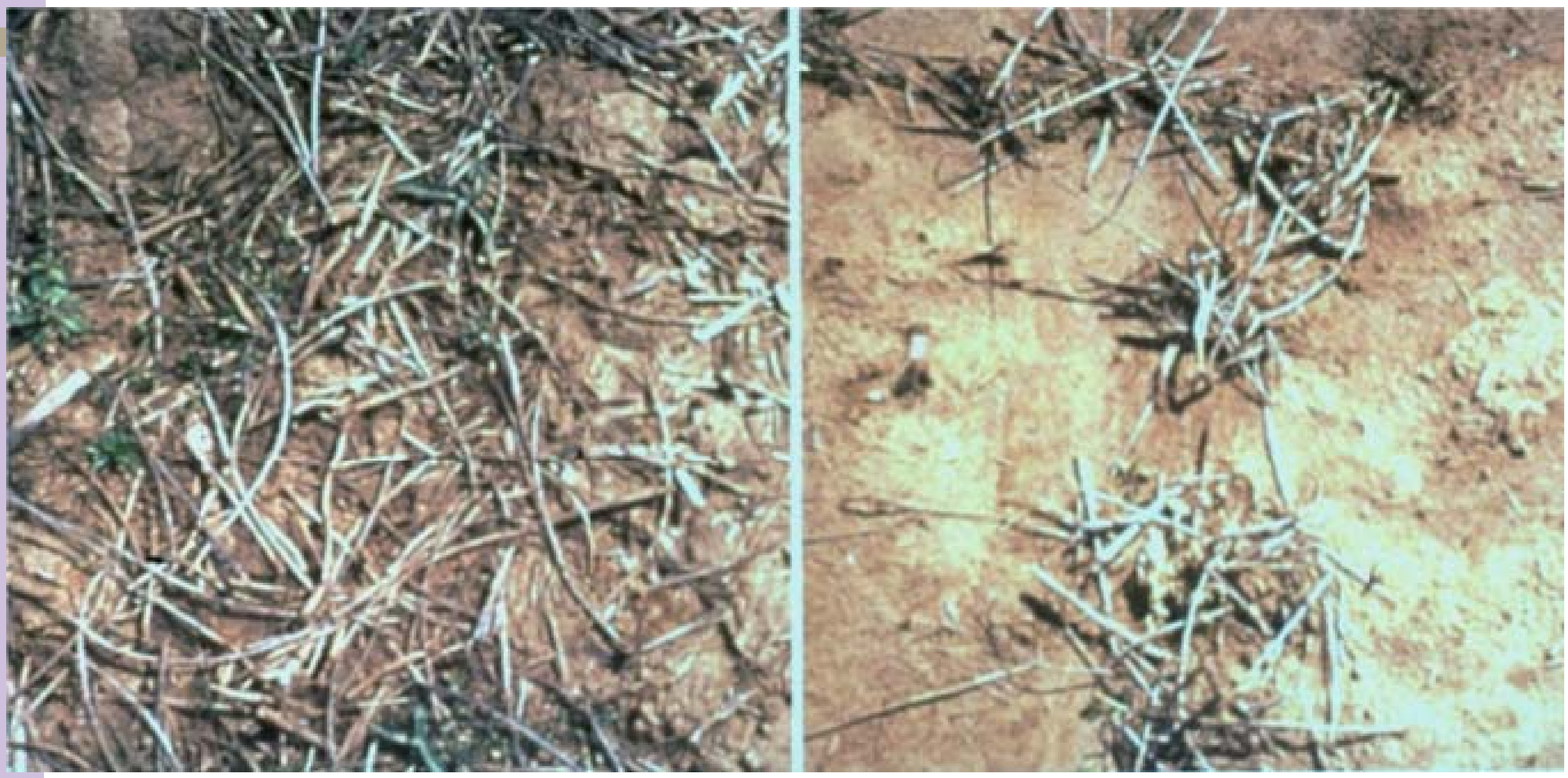
Earthworm burrow opening



Earthworm casts

Earthworms bury litter

Earthworms bury litter



Without earthworms   With earthworms