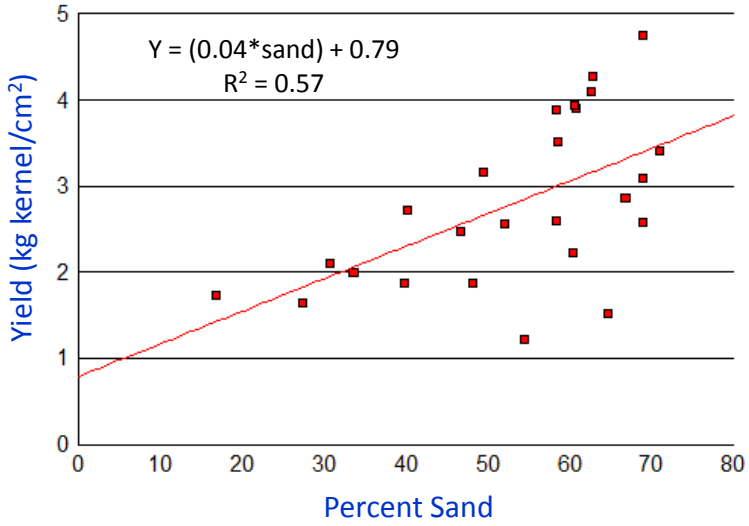
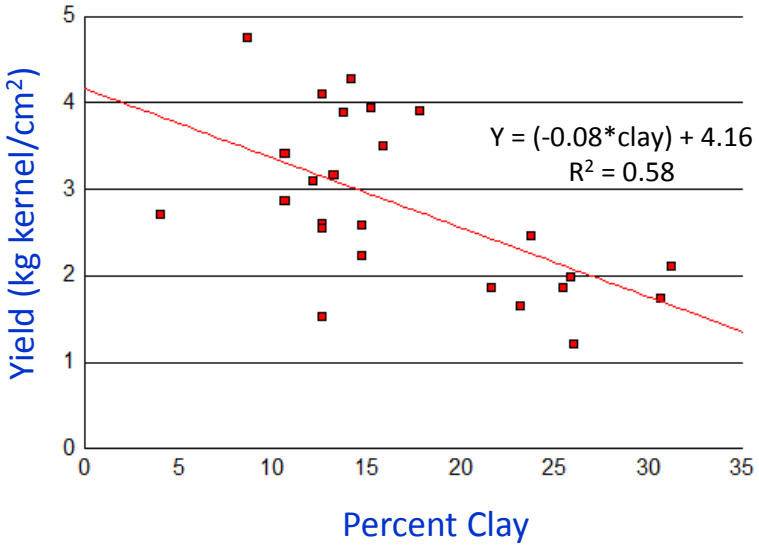
Soil Drainage

Dr. Jim Walworth
Dept. of Soil, Water & Environmental Sci.
University of Arizona

ARIZONA COOPERATIVE EXTENSION
THE UNIVERSITY OF ARIZONA • COLLEGE OF AGRICULTURE AND LIFE SCIENCES

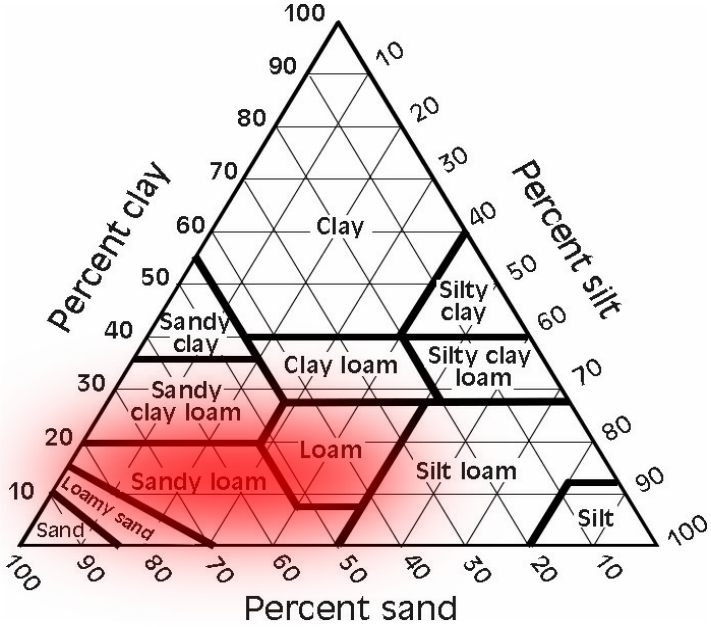




Pecans like well-drained soil. In Arizona pecan orchards, yields tend higher in soils with more sand and less clay

'Best' texture classes:

- loamy sand
- sandy loam
- loam
- sandy clay loam



Recognizing poorly-drained soils:

- Look for standing water following irrigation or runoff during irrigation indicate drainage problems
  - Water infiltration should be similar to the rates shown below

Soil Texture	Infiltration Rate (in/hr)
Sand	2
Sandy loam	1
Loam	0.5
Clay loam	0.25
Sandy clay loam	0.10

Refer to the NRCS Soil Survey

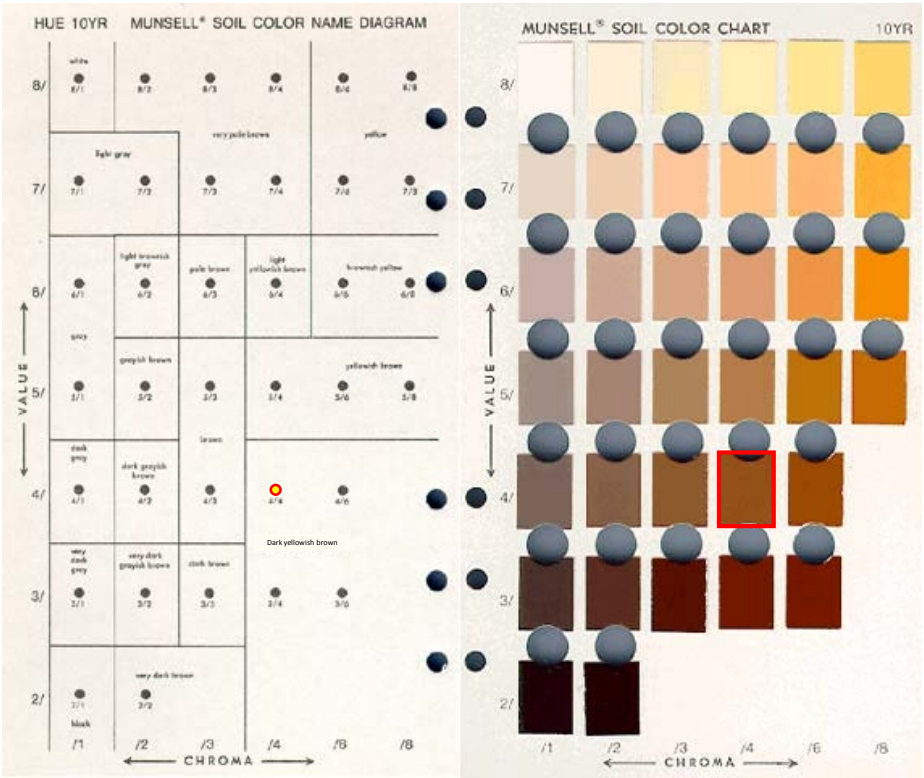
- ‘Drainage class’ refers to the frequency and duration of wet periods, and is indicated in Natural Resource Conservation Service soil maps
- Seven classes of natural soil drainage are recognized
  - excessively drained
  - somewhat excessively drained
  - well drained
  - moderately well drained
  - somewhat poorly drained
  - poorly drained
  - very poorly drained

Map unit symbol	Map unit name	Rating
CmA	Comoro sandy loam, 0 to 2 percent slopes	Well drained
Co	Comoro sandy loam, alkali variant	Well drained
Ct	Crot sandy loam	Somewhat poorly drained
Dv	Duncan loam, shallow variant	Well drained
Go	Gothard fine sandy loam	Moderately well drained
St	Stewart loam	Somewhat poorly drained
TrC	Torriorthents, hummocky	Excessively drained
Vn	Vinton loamy sand	Somewhat excessively drained

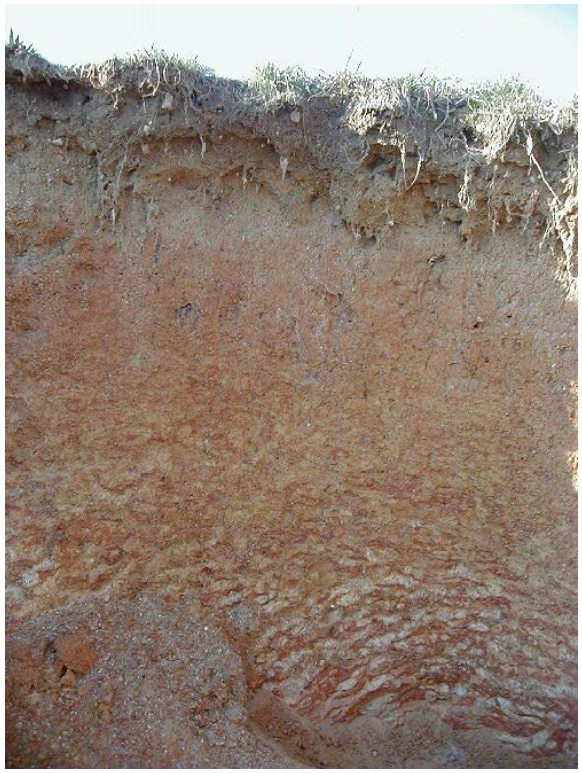
Soil color can indicate soil drainage status

Forested Cecil sandy loam

Ap - 0 to 8 inches; dark yellowish brown (10YR 4/4) sandy loam; weak medium granular structure;



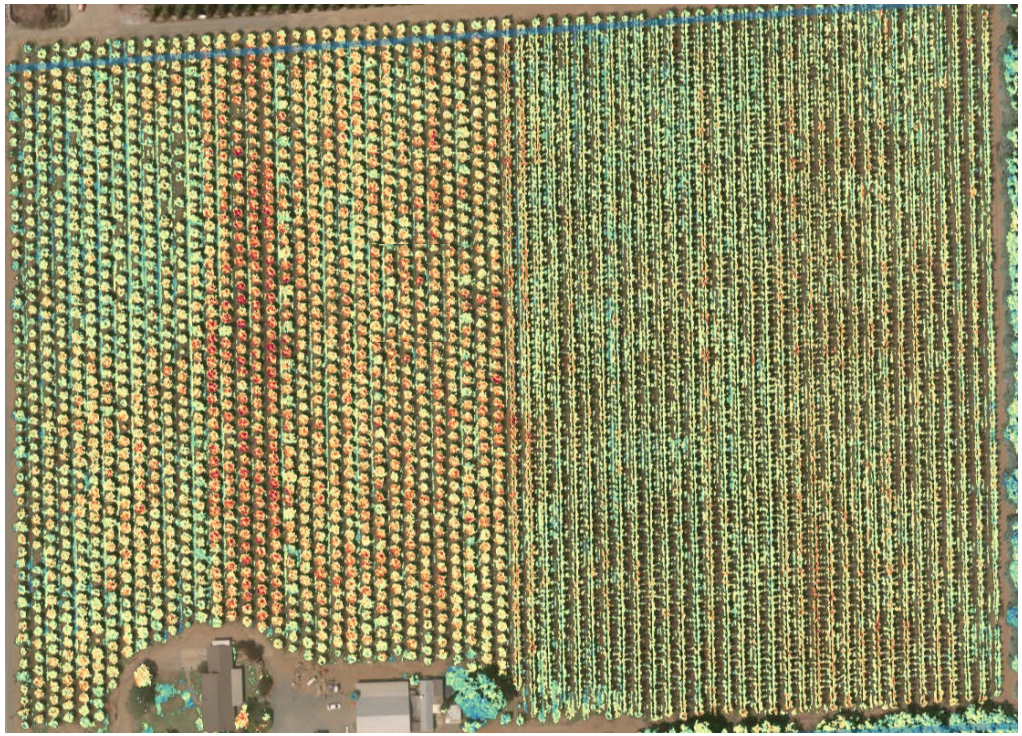
Mottling: Combination of bright and dull colors caused by *alternating wet and dry conditions*



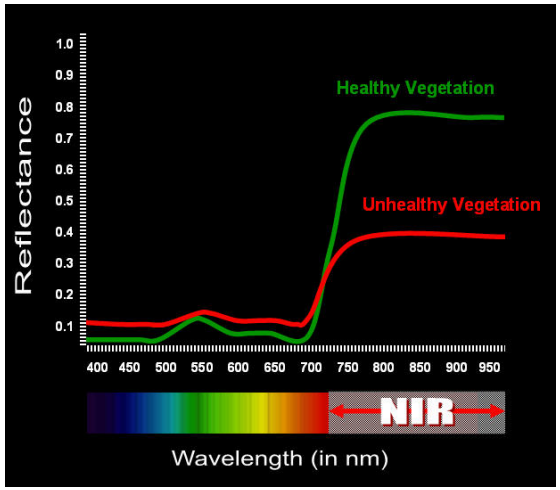
Poorly-drained soils often have distinctive colors

Gleying: Gray colors are caused by *prolonged wet conditions*

Look for tree stress



Spectral imaging to assess tree stress



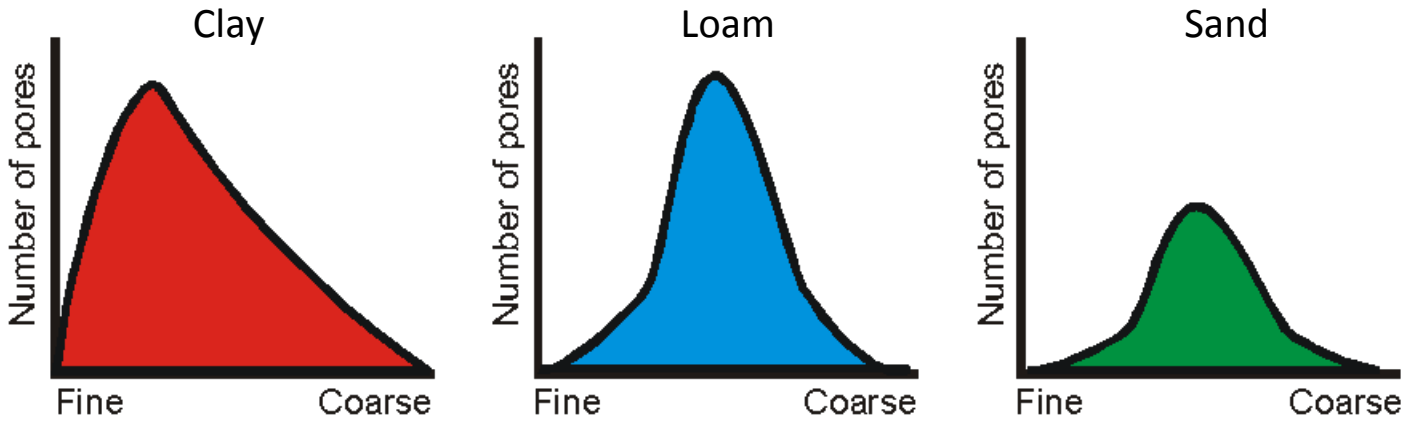
The size of soil pores is related to soil texture

In clayey soil

- Many pores
- Small average pore size

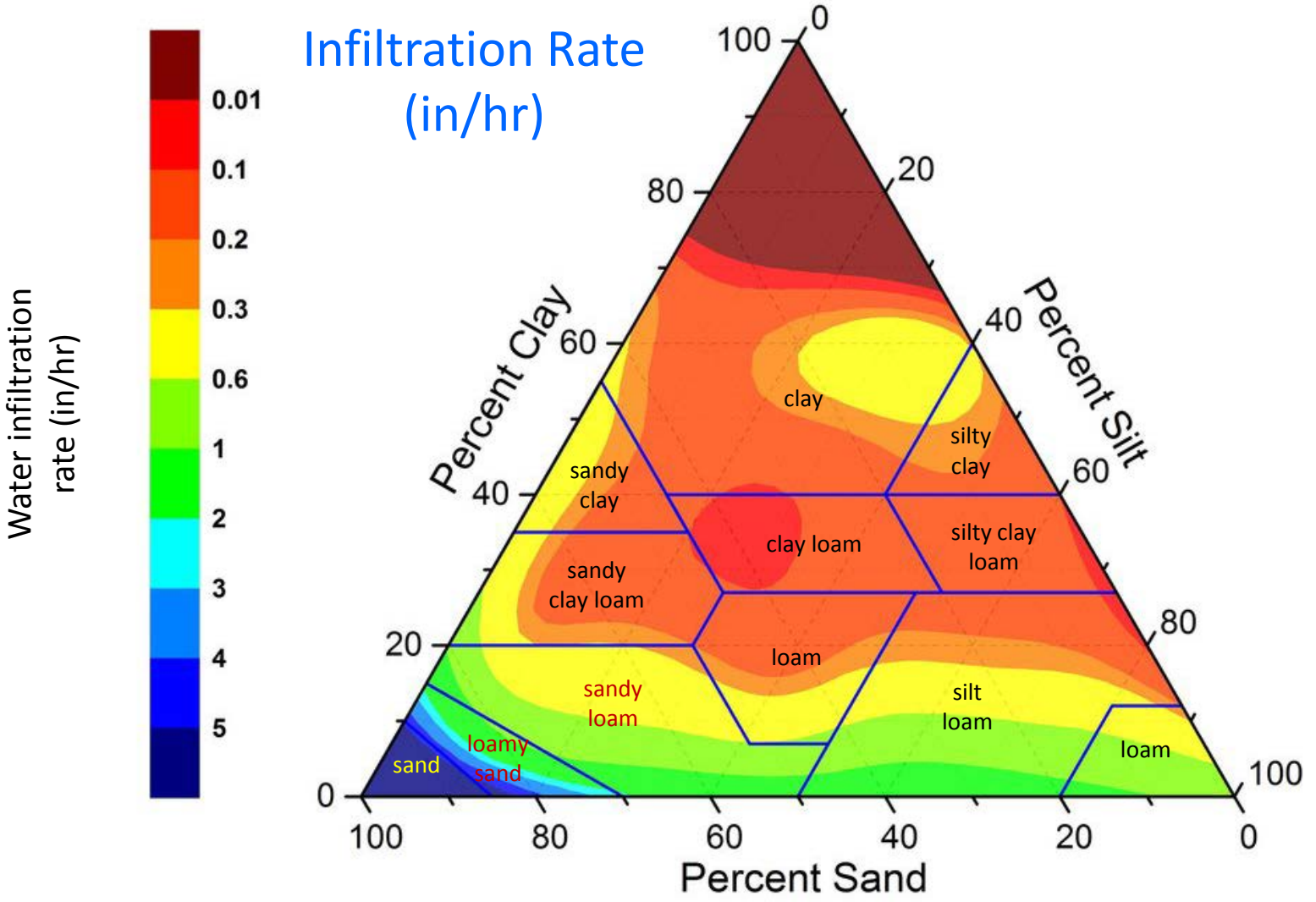
In sandy soil

- Fewer pores
- Large average pore size



Average pore size → 0.1 to 5 µm 0.4 to 12 µm 12 to 400 µm

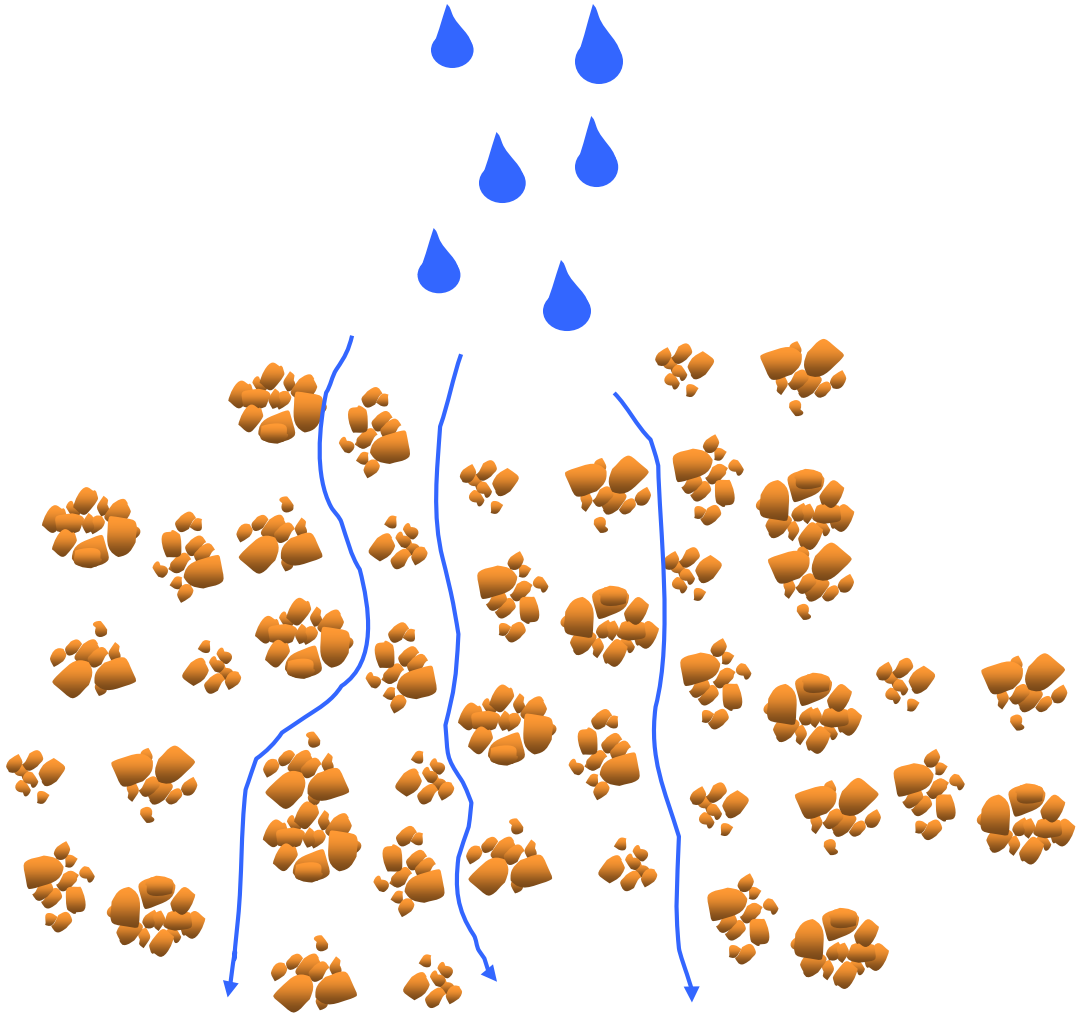
This is why the rate of water infiltration into soil (here in inches/hr) and soil drainage are closely related to soil texture



25.media.tumblr.com

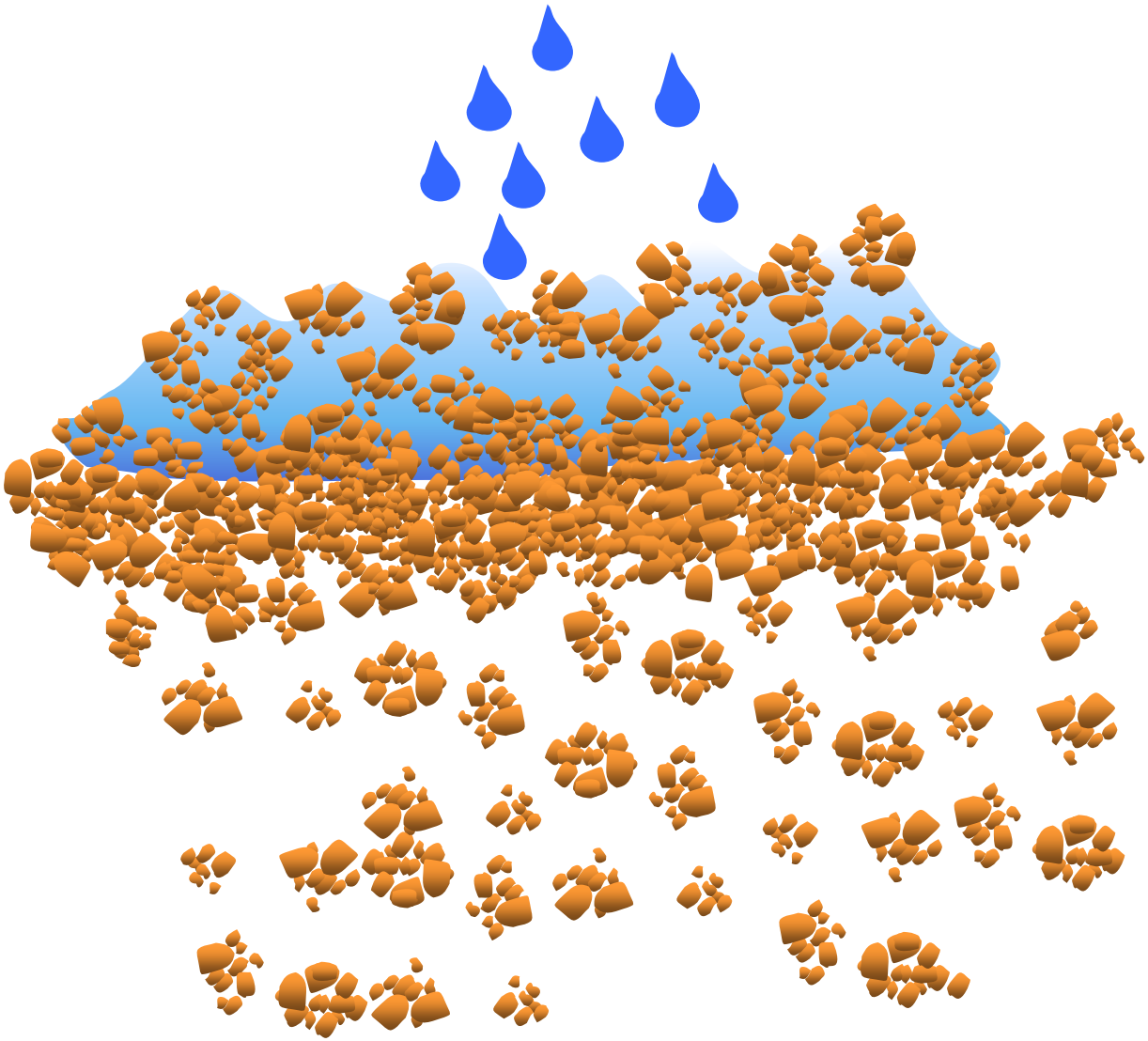
Soil structure (arrangement of soil particles) is also important

- Soil water infiltrates mostly in large pores between aggregates
- Plant roots grow mainly between aggregates
- Large inter-aggregate pores drain rapidly and supply oxygen to roots



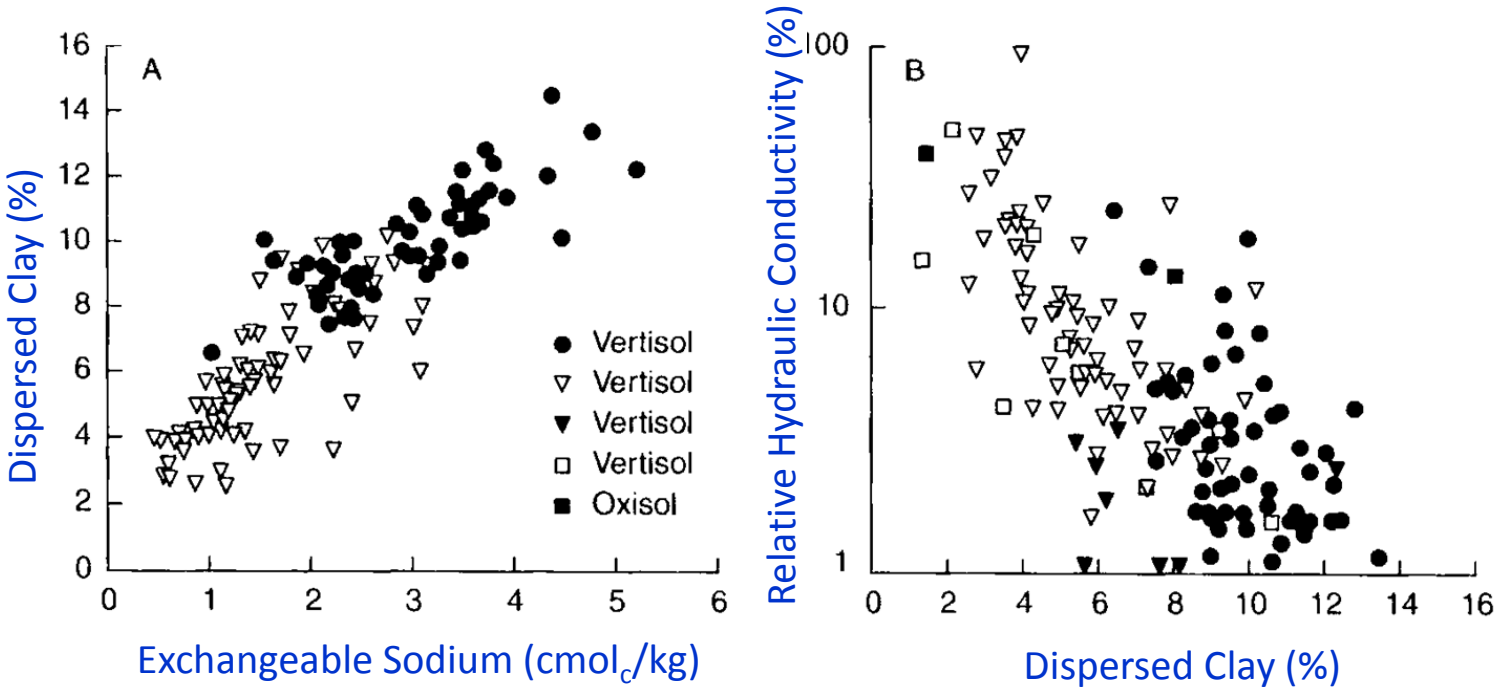
In all but the sandiest soils, excess sodium can cause clays to disperse

- Aggregates break down, allowing clay particles to move
- Dispersed clay plugs soil pores and impedes water infiltration and soil drainage



Increasing soil **exchangeable sodium** content

- weakens and breaks up soil aggregates
- *increases* clay dispersion
- *decreases* soil water flow (hydraulic conductivity)



To avoid sodium problems we recommend the following irrigation water limits

Soil Texture	**Sodium limit** (SAR -sodium adsorption ratio)
Clay, clay loam	< 3
Loam	3 - 8
Sand, loamy sand	8 - 10

- Maximum allowable SAR is dependent on soil texture
- Sandy soils can tolerate much higher SAR's than clay soils

Compacted soil layers impede drainage, water flow, air flow

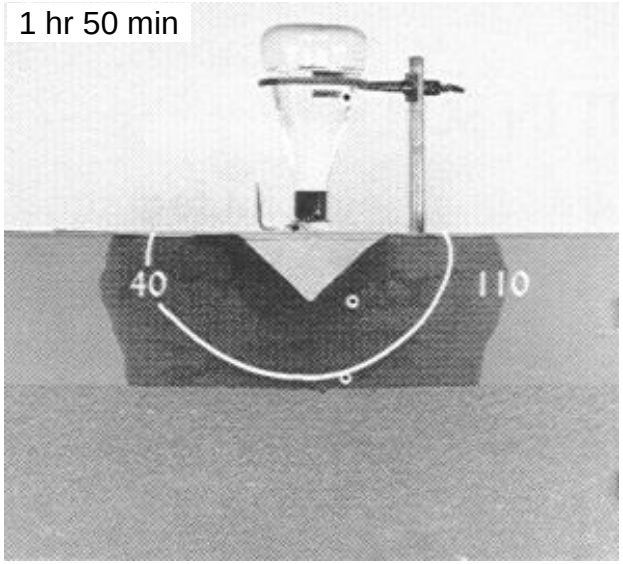
Compacted layer in a sandy loam

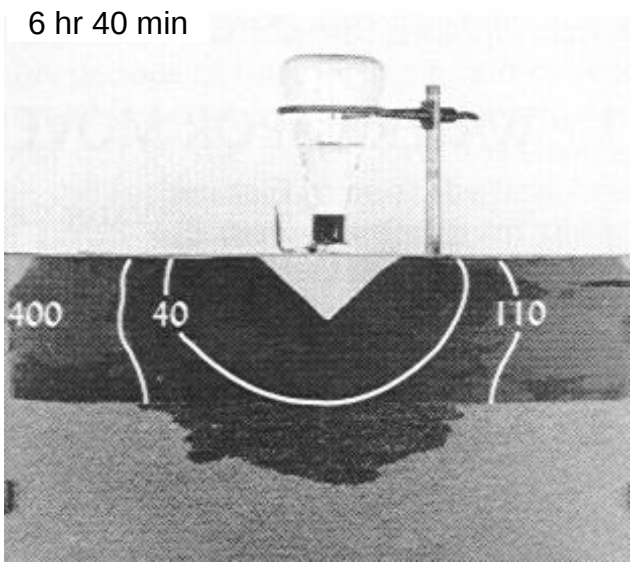
http://soilquality.org.au

Layers formed by disking and plowing

Saginaw Valley Research Farm, Michigan State Univ.

Water Movement in Layered Soils



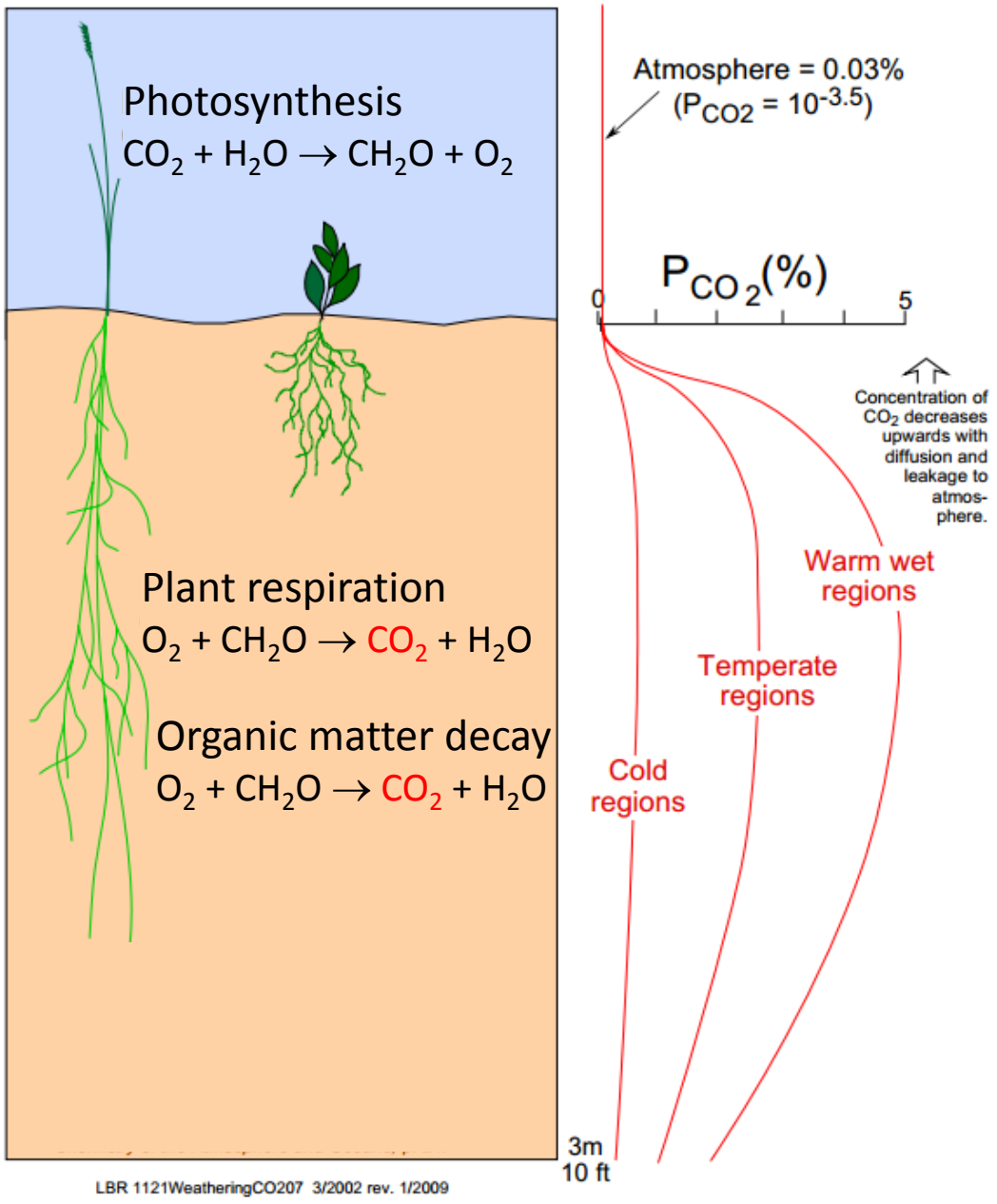


loam overlying sand

Wilford Gardener, Wash State Univ

Even in a well-drained soil, biological activity depletes soil oxygen

- Soil flora and fauna consume oxygen (O_2) and produce carbon dioxide (CO_2)
- Soil CO_2 builds up (CO_2 concentrations in soil are much greater than in the atmosphere)



When a soil is waterlogged, chemical changes take place

Chemical Change in Soil	Time (days)
Waterlogging starts	0 10 20 30 100
Oxygen decreases	♦
Carbon dioxide increases	♦
Absence of oxygen	♦------♦
Manganese (Mn^{2+}) increases	♦-------♦
Nitrate disappears	♦----------♦
Iron Fe^{3+} changes to Fe^{2+}	♦----------♦
Hydrogen sulfide appears	♦---------♦
Methane appears	♦

Setter and Belford. 1990. Waterlogging : how it reduces plant growth and how plants can overcome its effects. Journal of the Department of Agriculture, Western Australia

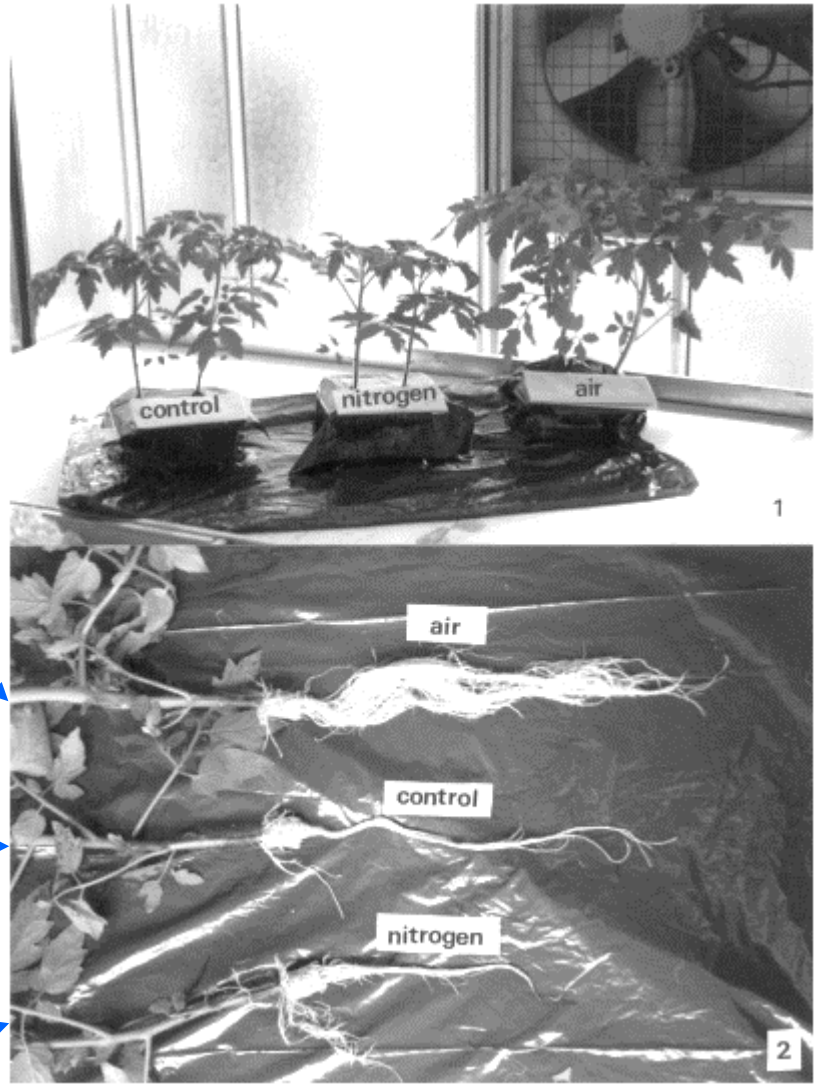
How does oxygen depletion affect plant roots?

Effect of oxygenation on aerial parts and roots growth of tomato plants

High oxygen supply: 11 to 14%
(5–7 ppm), obtained by bubbling compressed air through the nutrient solution

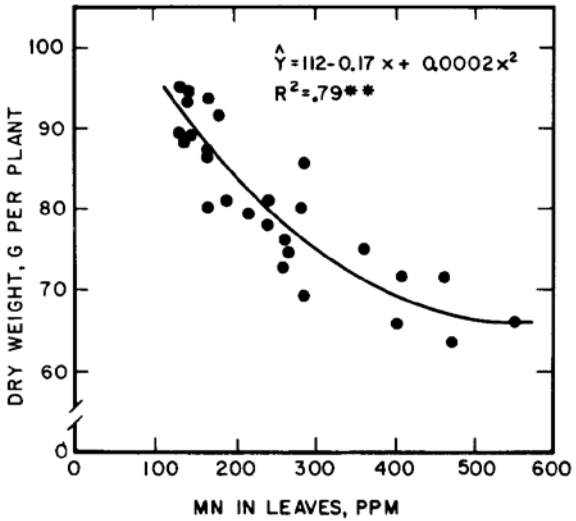
Moderate oxygen supply: 5.8 to 7%
(2.5–3 ppm), where the nutrient solution was not aerated (control)

Low oxygen supply: 0.8 to 1.5%
(0.4–0.7 ppm), obtained by bubbling compressed nitrogen (instead of air) through the nutrient solution

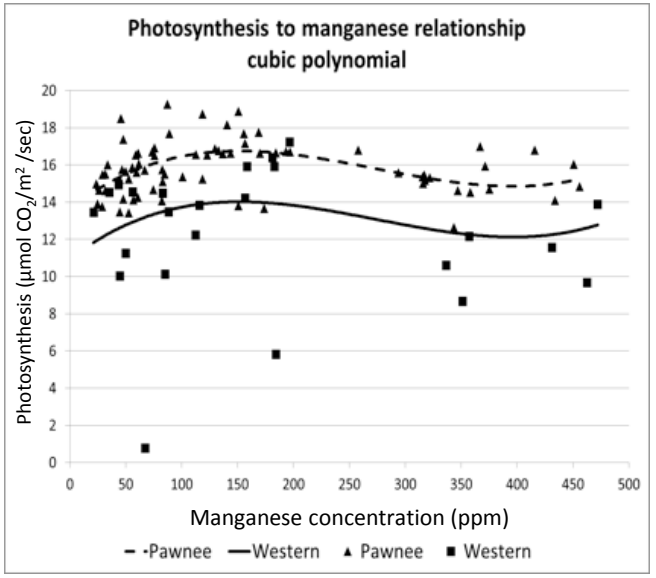


Manganese toxicity

Young leaves crinkled; with interveinal or marginal chlorosis



Relationship between leaf manganese concentration and dry weight of burley tobacco.



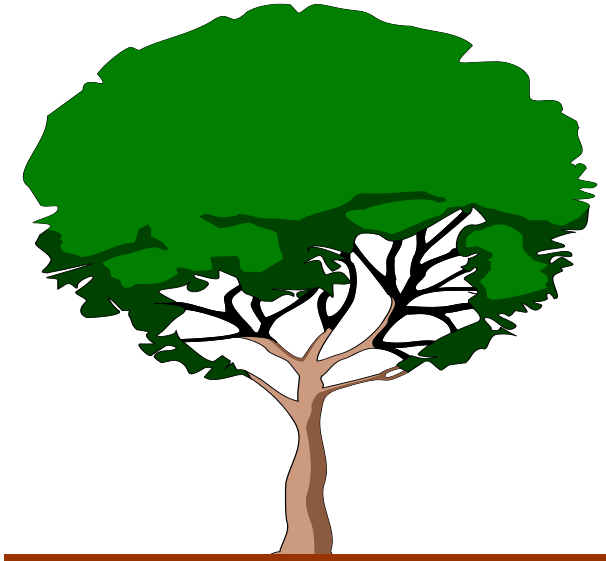
Pecan photosynthesis rate in relation to leaf manganese concentration.

J. Sherman and R. Heerema

Iron deficiency

- Worse in poorly-drained or over-watered alkaline soils
- Younger leaves have distinct interveinal chlorosis

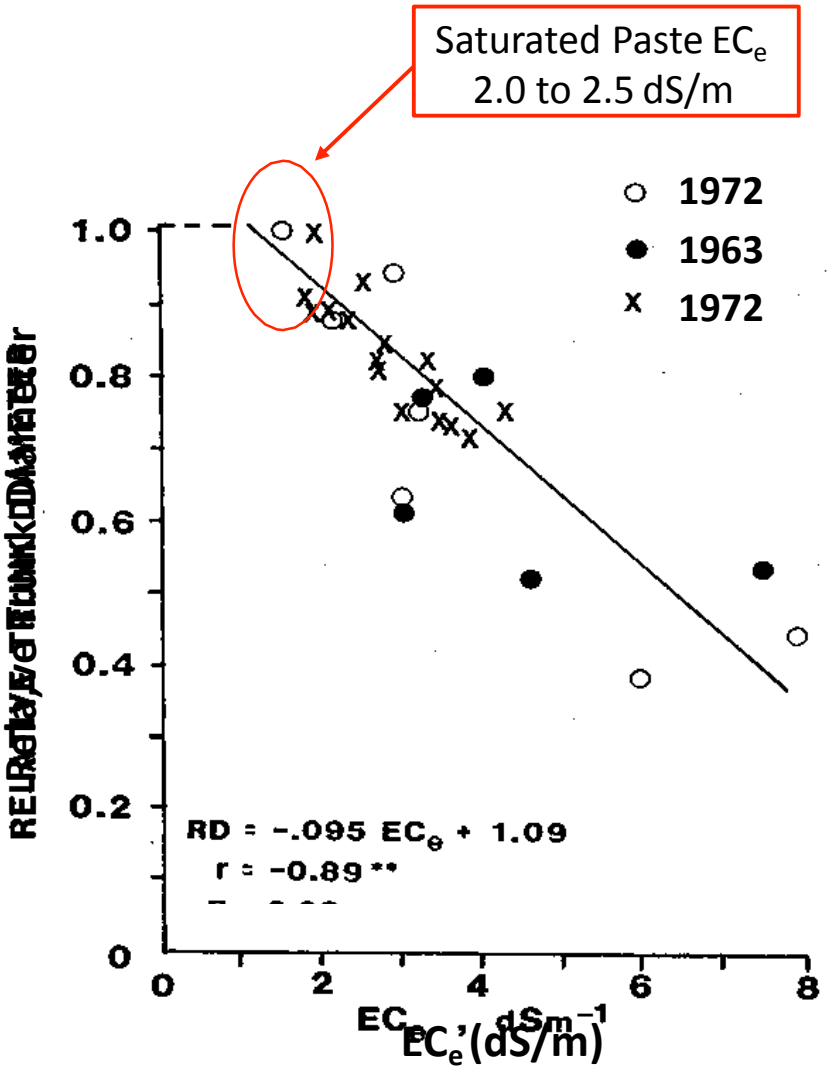
Salinity - anything that limits soil leaching can result in salt accumulation



Salts from irrigation water, mineral weathering, fertilizer, dust, etc.

Lack of leaching due to:

- Compacted layers
- Clayey soils
- Effects of sodium
- High water table
- Low precipitation
- High evapotranspiration



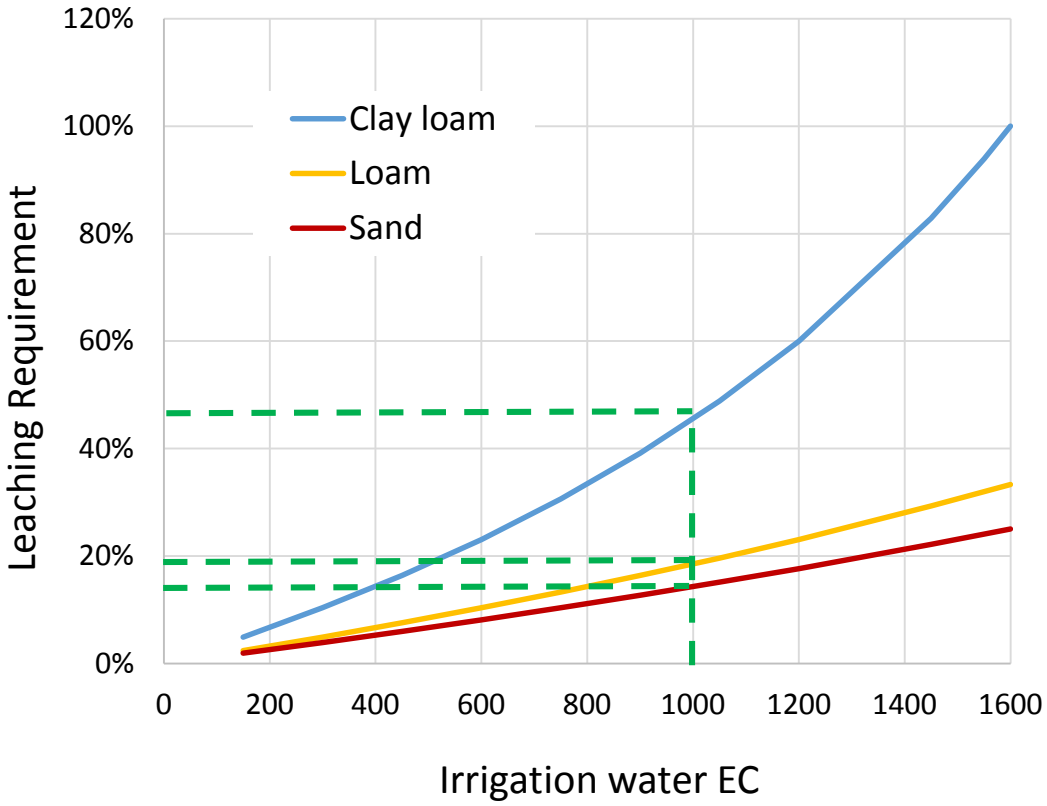
How much soil salinity is too much for pecans?

Miyamoto et al., 1986

We rely on leaching to maintain low soil salt levels

The leaching requirement (LR) is the excess water (beyond tree needs) that must be applied to keep salts at a level that will not reduce yield

- LR increases as irrigation water salinity increases
- LR increases as soil clay content increases

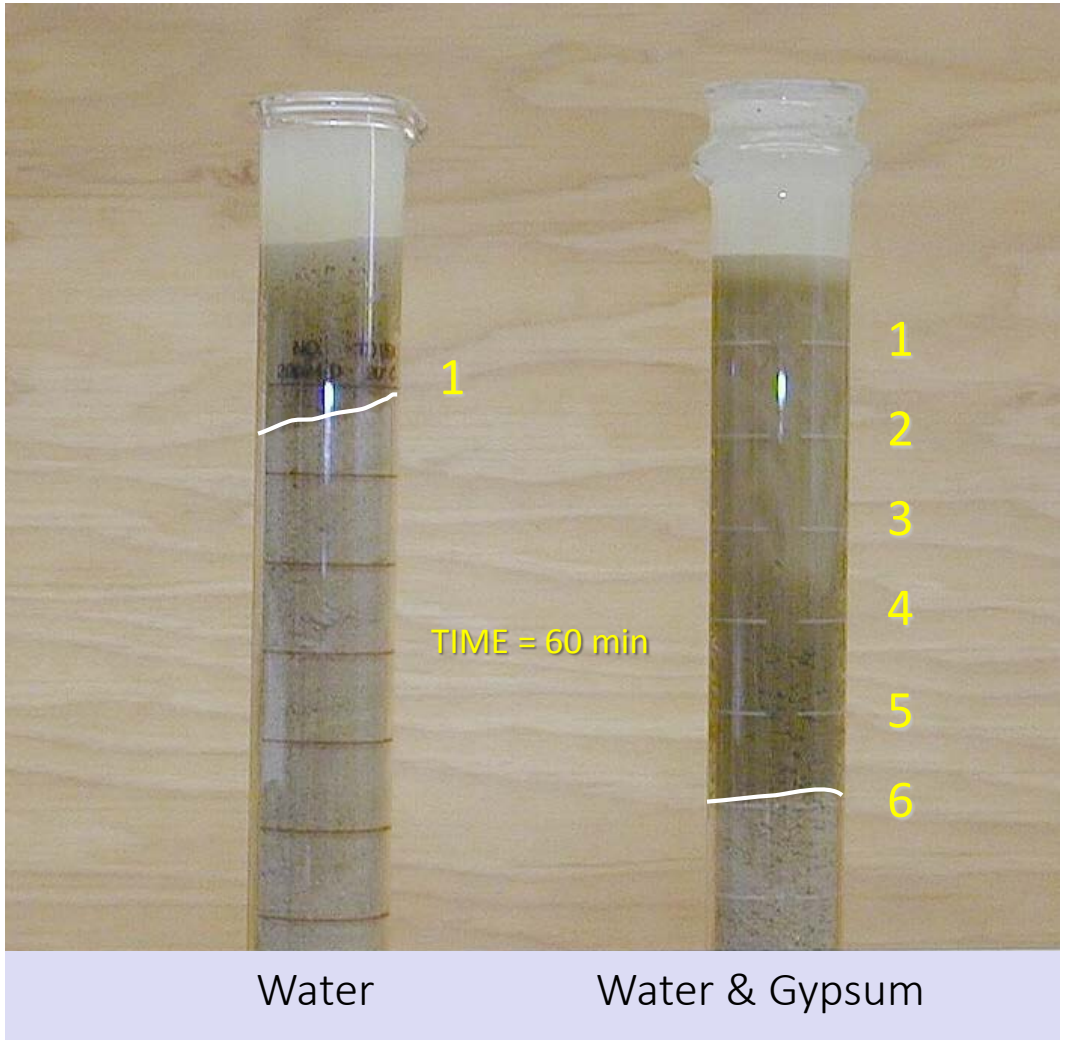


LR for 1000 ppm water

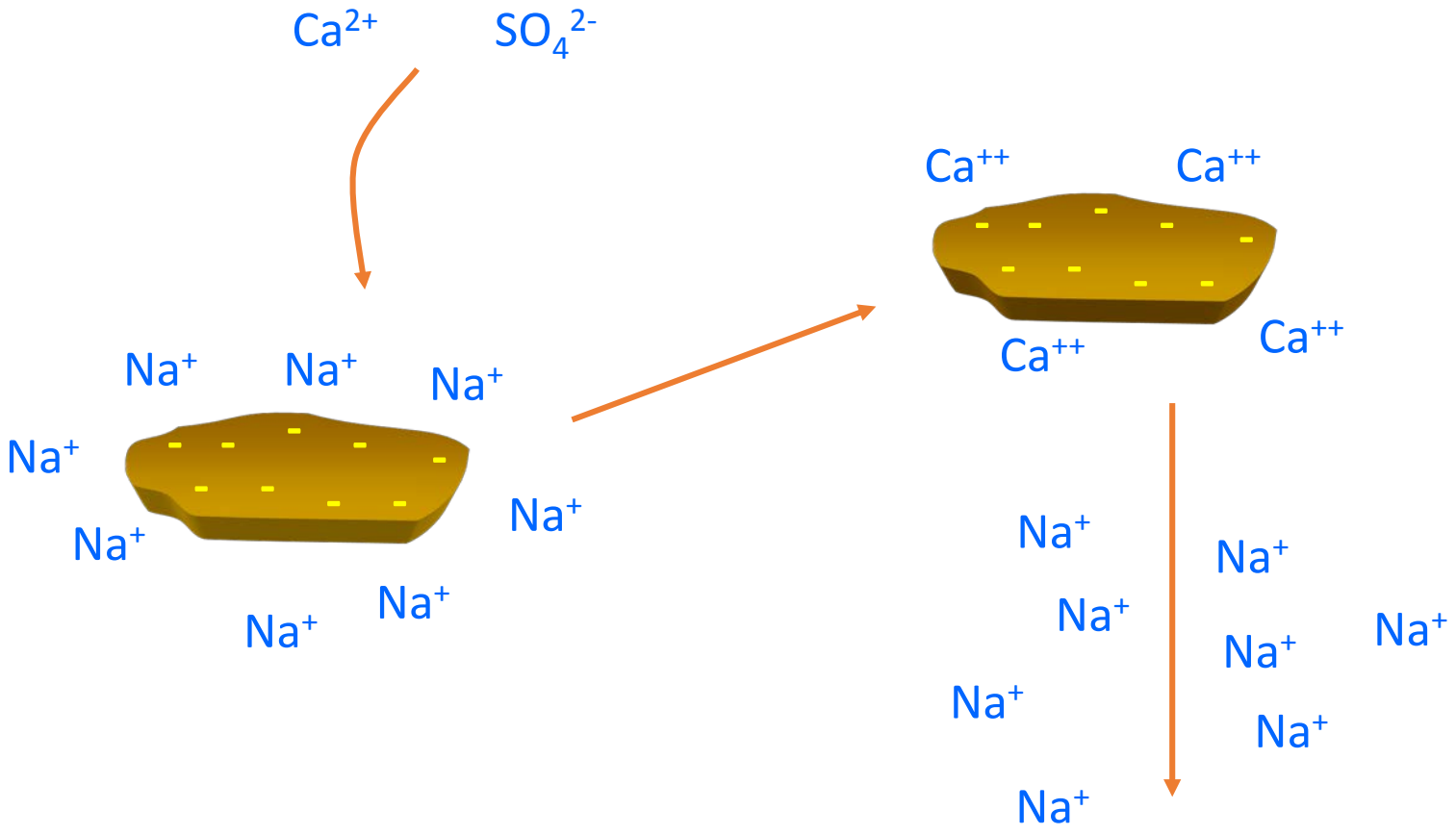
Soil texture	LR
clay, clay loam	45%
loam	19 – 45%
sand, loamy sand	14 – 19%

Leaching may be difficult in soils with high levels of sodium

Soils with high levels of soil sodium can be treated by increasing soluble soil calcium. Gypsum ($CaSO_4 \cdot 2H_2O$) is the most commonly used soil amendment.



Replacing exchangeable sodium (Na^+) with calcium (Ca^{2+}) before leaching will improve and stabilize soil structure



Calcareous Soils: Free Lime

- 'Free lime' is calcium carbonate (or lime) in the soil
  - We test for free lime by looking soil effervescence (bubbling) upon addition of acid
  - Most desert soils are calcareous

Soil Complete Test	Method	Result	Units	Levels
pH	1:1	8.4	SU	Very High
Electrical Conductivity, EC	1:1	0.26	dS/m	Low
Calcium, Ca	NH4OAc (pH 8.5)	2,400	ppm	High
Magnesium, Mg	NH4OAc (pH 8.5)	250	ppm	High
Sodium, Na	NH4OAc (pH 8.5)	42	ppm	Low
Potassium, K	NH4OAc (pH 8.5)	500	ppm	Very High
Zinc, Zn	DTPA	0.70	ppm	Medium
Iron, Fe	DTPA	4.9	ppm	Medium
Manganese, Mn	DTPA	4.4	ppm	Medium
Copper, Cu	DTPA	2.1	ppm	High
Nickel, Ni	DTPA	0.15	ppm	
Nitrate-N, NO3-N	Cd-Reduction	3.1	ppm	Low
Phosphate-P, PO4-P	Olsen	6.8	ppm	Low
Sulfate-S, SO4-S	Hot Water	3.9	ppm	Low
Boron, B	Hot Water	0.85	ppm	Medium
Free Lime, FL	Acid Test	Low		
ESP	Calculated	1.2	%	
CEC	Calculated	15.5	meq/100g	

Soil Amendments for Sodium

➔ Sulfuric Acid (H_2SO_4)

In soils with free lime (**calcareous soils**), acids are effective amendments for correcting or preventing sodium problems

$$H_2SO_4 + CaCO_3 \rightarrow CO_2 + H_2O + CaSO_4$$

- H_2SO_4 is dangerous material
- Can be applied to soil or water-run
- Rates are commonly 1-3 Mt/ha
- 0.6 kg sulfuric acid ≈ 1 kg gypsum

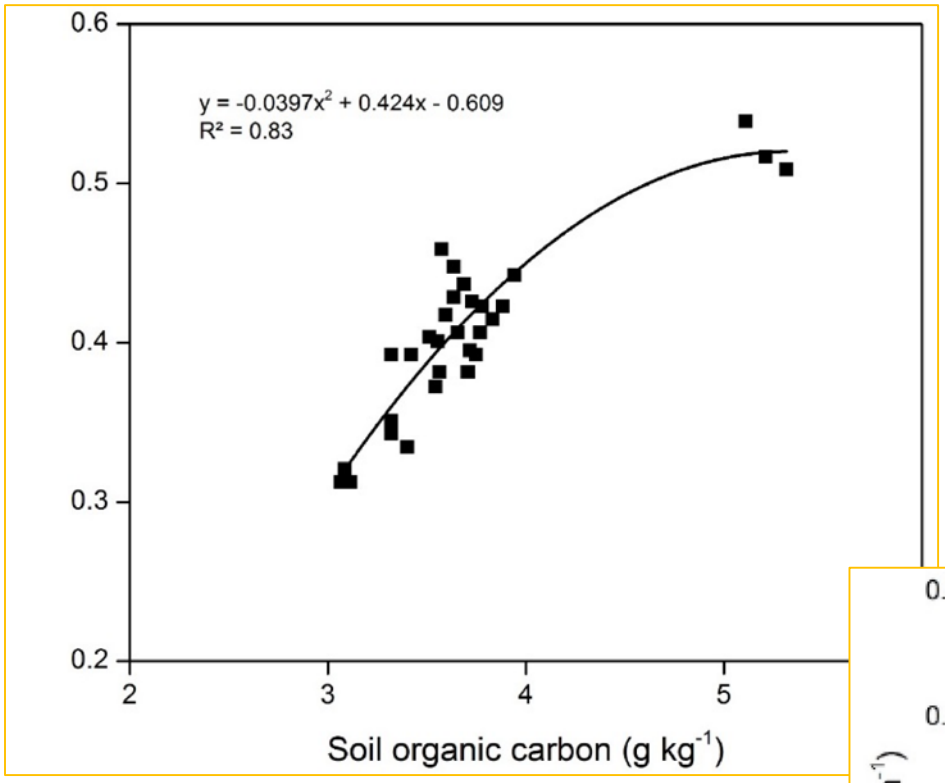
Soil Amendments for Sodium

➔ Elemental Sulfur

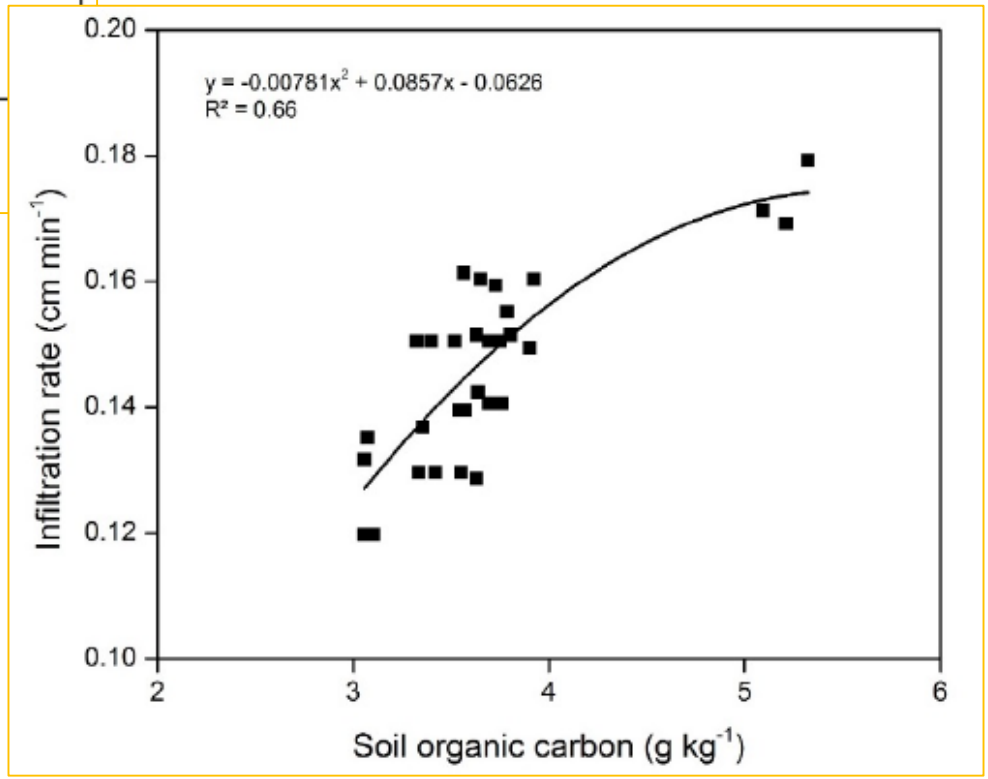
- S is an effective acid-forming amendment
  - Soil microorganisms use S to produce sulfuric acid
  - The sulfuric acid reacts with $CaCO_3$ to release Ca
  - Only works in **calcareous soils**

$$S + ½O_2 + CO_2 + 2H_2O \rightarrow H_2SO_4 + CH_2O$$

- Requires microbial activity to react
  - Conversion to sulfuric acid takes time
    - several weeks
    - faster in warm soils
  - 0.4 kg S ≈ 1 kg gypsum



Addition of soil organic matter can increase particle aggregation and improve water infiltration and soil drainage



Effects of Long Term Application of Inorganic and Organic Fertilizers on Soil Organic Carbon and Physical Properties in Maize–Wheat Rotation. Singh Brar et al., Agronomy 2015, 5(2), 220-238;

Shredding pruned wood adds organic matter to pecan orchard soils

NMSU, Jane Moorman

Southwest Farm Press

Crop covers increase soil organic matter and aggregation, can improve water infiltration and soil drainage

Tillage can improve drainage of soil with impermeable layers

- Tillage may be needed to increase soil permeability if restrictive layers (caliche, hardpans, textural layering) are present
  - methods include ripping, trenching
- Tillage is effective only if combined with application of proper leaching requirements

Effect of chiseling on EC_e of a silt loam (dS/m)

	Soil Depth		
Treatment	0-12 in	12-24 in	24-36 in
Chiseled	2.0	4.9	4.5
Unchiseled	3.5	5.7	5.1

* Chiseled at 20 to 24 inches depth

Helmers and Miyamoto

Thank you