GEOLOGY 408/508

SOIL AERATION AND TEMPERATURE

CHAPTER 7

Brady & Weil, Rev. 14th ed.

SOIL AERATION - THE PROCESS

Excess moisture:

- fills pores with water, limits O_2 availability
- waterlogged or water saturated
- hydrophytes- adapted to waterlogged soils
- most plants need O_2 from soil (houseplants too)

Gaseous interchange:

- via mass flow and diffusion
- most by diffusion in response to partial P difference or gradient
- gradient for each individual gas (FIGURE 7.3)

MEANS OF CHARACTERIZING SOIL AERATION

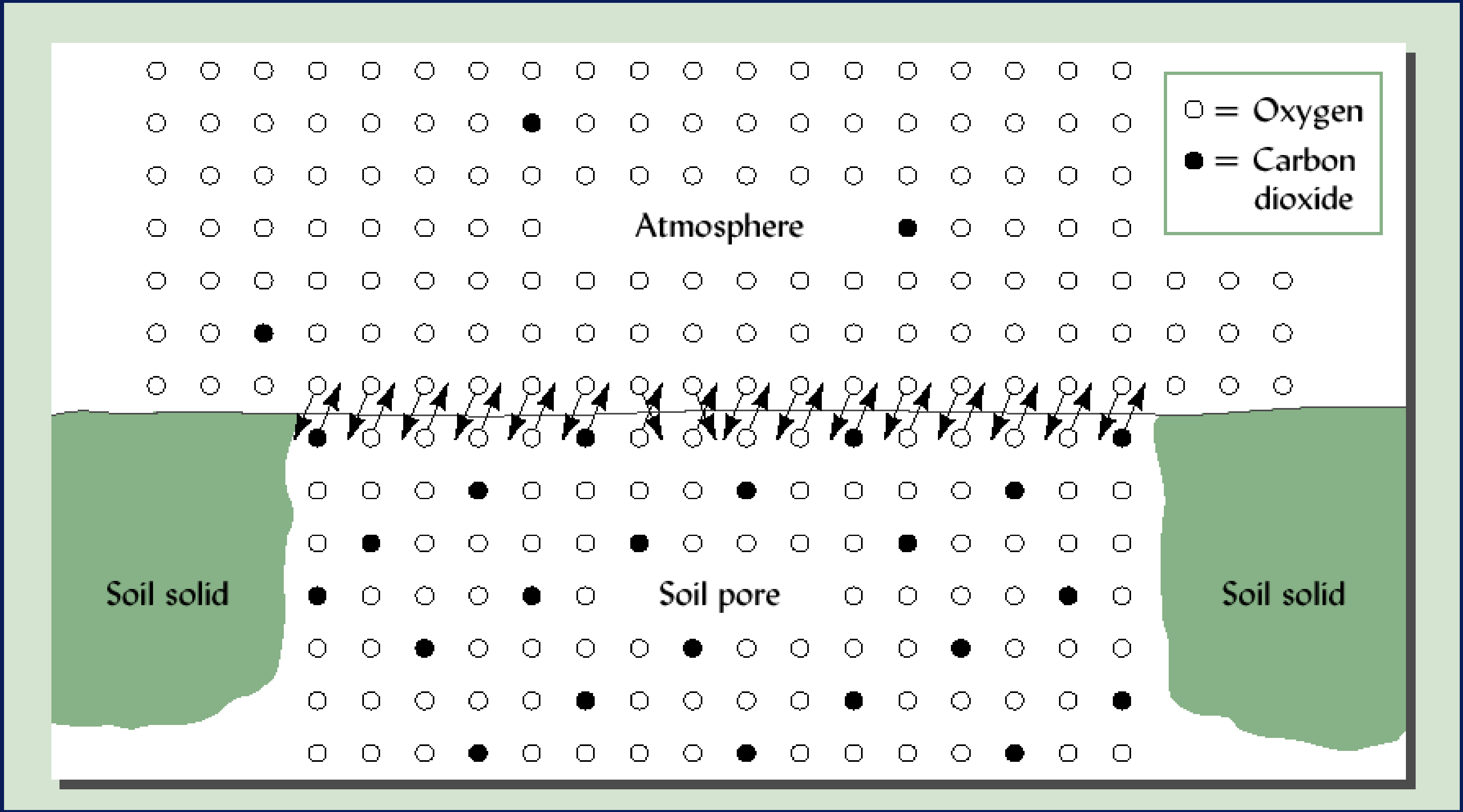
Gaseous composition of soil air:

- O_2: ~19% to <5% (atmos = 21%)
    - may be ~0% in waterlogged soils
- CO_2: 0.35% - 10% (atmos = 0.035%)
- Other gasses: H_2O vapor - nearly saturated
  H_2S, CH_4, C_2H_2

Air-filled porosity:

- >20% is best for microbial growth
- O_2 diffusion very slow in H_2O filled pores
- when low, H_2O fills pores & may have anaerobic conditions

PROCESS OF GAS DIFFUSION



The process of diffusion between gases in a soil pore and in the atmosphere. The total gas pressure is the same on both sides of the boundary. The gasses respond to differences in their partial pressure in the two zones (FIGURE 7.3)

OXIDATION-REDUCTION (REDOX) POTENTIAL

Redox reactions:

$$2FeO + 2H_2O \Leftrightarrow 2FeOOH + 2H^+ + 2e^-$$

(Fe^{++}) (Fe^{+3})

- can measure redox potential, E_h, with Pt electrode
- *oxidizing agent*: accepts electrons easily
- *reducing agent*: supplies electrons easily

Role of oxygen:

- strong ozidizing agent

$$0.5O_2 + 2H^+ + 2e^- \Leftrightarrow H_2O$$

OXIDATION-REDUCTION (REDOX) POTENTIAL

Combined reaction:

$$2FeO + 2H_2O \Leftrightarrow 2FeOOH + 2H^+ + 2e^-$$

$$0.5O_2 + 2H^+ + 2e^- \Leftrightarrow H_2O$$

$$2FeO + 0.5O_2 + H_2O \Leftrightarrow 2FeOOH$$

Other electron acceptors:

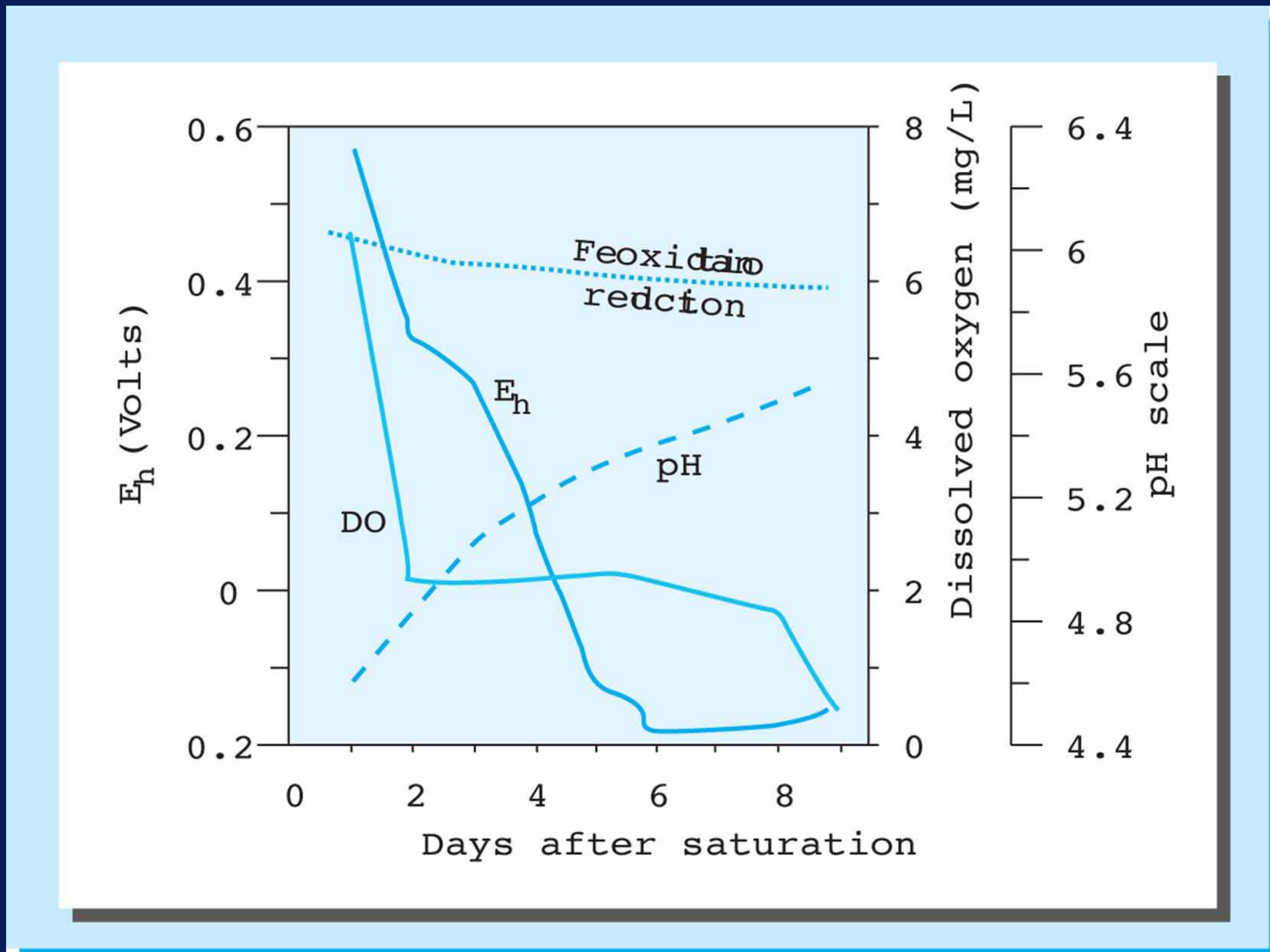
$$NO_3^- + 2e^- + 2H^+ \Leftrightarrow NO_2^- + H_2O$$

N(V) N(III)

- if sufficient NO_3^- is present, Eh stays near 0.38-0.32 V

See FIGURES 7.5 & 7.6 and TABLE 7.1 for other species common in soils

CHANGES IN SOIL CHEMISTRY FOLLOWING WATER SATURATION OF A SILT LOAM A HORIZON

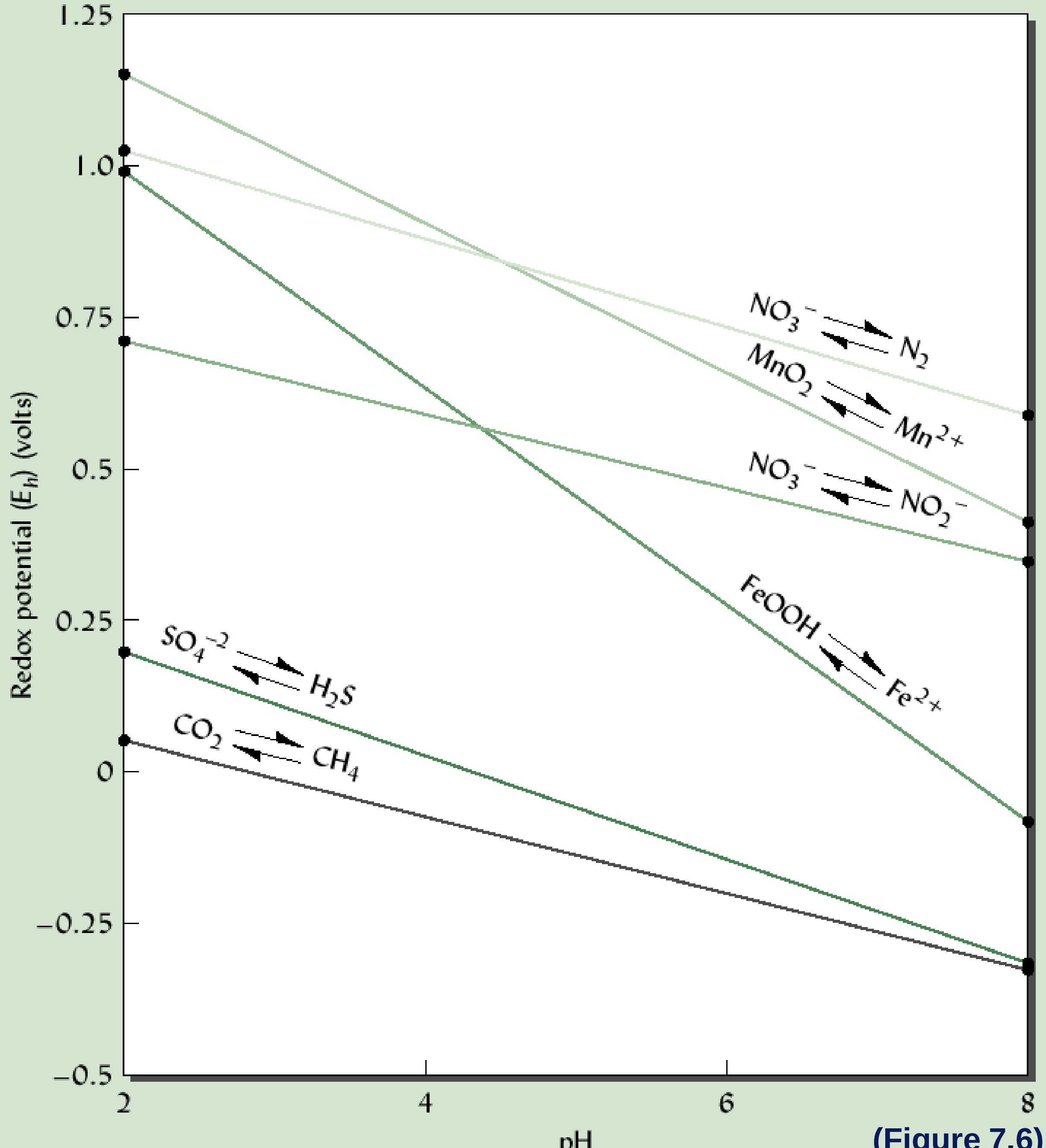


Eh-pH Diagram

The effect of pH on the redox potential, E_h

E_h decreases as pH rises

Different reactions occur as E_h is lowered



(Figure 7.6)

FACTORS AFFECTING SOIL AERATION

Drainage of excess water:

- drainage from macropores replenishes soil air
- texture, Db,aggregate stability, % OM, biopore formation help determine macropore for'm

Rates of respiration in the soil:

- increased microbial respiration changes gas content/composition

Subsoil versus topsoil:

- subsoils generally have less O_2 than topsoils
- total & macro pore space lower in subsoils
- low OM at depth will yield higher O_2

FACTORS AFFECTING SOIL AERATION

Soil heterogeneity:

- profile: general decrease in O_2 with depth; may be pockets of low O_2
- tillage: short-term increases; uniformity depends on method
- large macropores: may periodically fill with H_2O
- plant roots: depending upon plant, depletetion or enrichment of O_2 may occur at roots

Seasonal differences:

- spring = wet & lower gaseous exchange
- summer = drier & increased gaseous exchange

Effects of vegetation:

- root respiration
- "H_2O pumping" lowers water content/table

ECOLOGICAL EFFECTS OF SOIL AERATION

Organic residue degradation:

- organic compounds degrade via oxidative processes
- poor aeration slows rate of decay

Oxidation-reduction of elements:

- level of soil O_2 determines forms of the
  - -nutrient elements C, N, S, Fe, Mn
  - toxic elements As, Cr, Se

Soil color affected by compounds of Fe & Mn:

- bright colors indicate oxidizing conditions
- dark or gray colors indicate reducing cond's

ECOLOGICAL EFFECTS OF SOIL AERATION

Effects on activities of higher plants:

- plant species vary widely in tolerance to low O_2
- differences in tolerance at different life stages
- low O_2 levels constrain root respiration, plant may wilt

Soil compaction & aeration:

- compaction does limit exchange os gases
- greater problem is generally resistance to root penetration

AERATION IN RELATION TO SOIL AND PLANT MANAGEMENT

Soil structure & cultivation:

- maintenance of stable structure ⇒ good aeration
- macropores encourage by additions of OM
- more difficult to maintain in low tillage conditions

Container-grown plants:

- waterlogged soils frequent problems
- fine pores in mineral soils hold water
- porous potting mixes especially prepared for this
- many mixes have no mineral soil

Tree & lawn management:

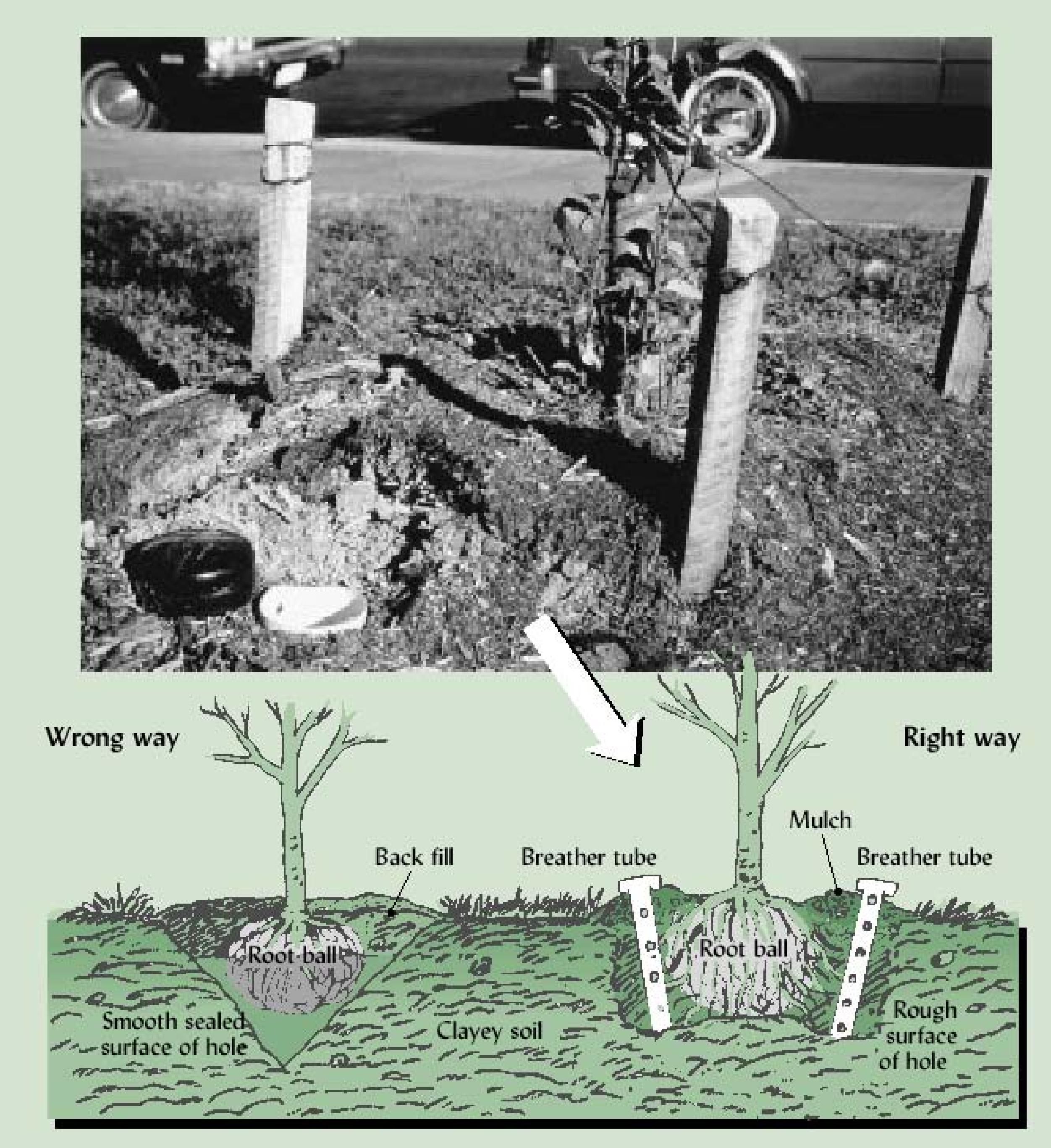
- take care to prepare soil when planting trees (Fig 7.12)
- remember most tree roots are near surface
- core cultivation for lawns

PROVIDING AIR TO TREE ROOTS

Providing a good supply of air to tree roots can be a problem, especially when trees are planted in fine-textured, compacted soils of urban areas.

A machine-dug hole with smooth sides will act as a “tea cup” and fill with water, suffocating tree roots.

Breather tubes, a larger rough-surfaced hole, and a layer of surface mulch in which some fine tree roots can grow are all measures that can improve the aeration status of the root zone. **(FIGURE 7.11)**



PROTECTION OF VALUABLE TREES DURING LANDSCAPE GRADING OPERATIONS

Use dry well

Thin layer of soil over large root system can suffocate roots (esp when compacted)

(Figure 7.14)

TOLERANCE OF SELECTED PLANTS TO A HIGH WATER TABLE

TABLE 7.4 Examples of Plants with Varying Degrees of Tolerance to a High Water Table and Accompanying Restricted Aeration

The plants in the leftmost column commonly thrive in wetlands. Those in the rightmost column are very sensitive to poor aeration.

Plants adapted to grow well with a water table at the stated depth				
<10 cm	*15 to 30 cm*	*40 to 60 cm*	*75 to 90 cm*	*>100 cm*
Bald cypress	Alsike clover	Birdsfoot trefoil	Beech	Arborvitae
Black spruce	Bermuda grass	Black locust	Birch	Barley
Common cattail	Black willow	Bluegrass	Cabbage	Beans
Cranberries	Cottonwood	Linden	Corn	Cherry
Duckgrass	Creeping bentgrass	Mulberry	Hairy vetch	Hemlock
Phragmites grass	Deer tongue	Mustard	Millet	Oats
Maiden cane	Eastern gamagrass	Red maple	Peas	Peach
Mangrove	Ladino clover	Sorghum	Red oak	Sand lovegrass
Pitcher plant	Loblolly pine	Sycamore		Sugar beets
Reed canary grass	Orchard grass	Weeping love grass		Walnut
Rice	Redtop grass	Willow oak		Wheat
Skunk cabbage	Tall fescue			White pine
Spartina grass				
Swamp white oak				
Swamp rose mallow				
Water tupelo				

WETLANDS & THEIR POORLY AERATED SOILS

Defining a wetland:

- Soils that are water-saturated near the surface for prolonged periods when soil temperatures and other conditions are such that plants and microbes can grow and remove soil oxygen, thereby assuring anaerobic conditions
- Major difficulty is in defining the drier end of the wetland
- Wetland delineation:

    1. A wetland hydrology or water regime
    2. Hydric soils
    3. Hydrophytic plants

WETLANDS & THEIR POORLY AERATED SOILS

Wetland hydrology:

- Balance between inflows & outflows determines degree & duration of wetness
- Hydroperiod is the temporal fluctuation of water level
  - may be daily or seasonally
  - temperature during saturation period is important
  - growing season may differ from saturation period
  - it is the anaerobic condition, not just saturation, that creates a wetland
- Residence time is important for maintaining wetland conditions - draining destroys wetland functions

WETLANDS & THEIR POORLY AERATED SOILS

Wetland hydrology, continued:

- **Indicators of saturated conditions:**
  - **water stains on trees & rocks**
  - **sediment coating on plant leaves & litter**
  - **drift lines of branches, twigs, other debris**
  - **trees with extensive root masses above ground**
  - **hydric soils**

Hydric soils: "A hydric soil is a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part."

- **subject to periods of saturation**
- **undergo reduced conditions for substantial periods**
- **exhibit hydric soil indicators**

BEAVER HOUSE IN TIDAL MARSH AT LOW TIDE

WETLANDS & THEIR POORLY AERATED SOILS

Hydric soil indicators:

- features associated with saturation & reduction
- redoximorphic features:
  - gray zones of reduced/depleted Fe
  - may be gray to blue-green colors
  - reddish zones of oxidized Fe
  - hard black Mn nodules
  - reddish oxidized Fe around root channels
- indicative of wetland soil when present in upper horizons

- see Box 7.2

- **Publication: Field Indicators of Hydric soils in the United States: (Updates at:** http://soils.usda.gov/use/hydric/) http://www.dlese.org/dds/catalog_DLESE-000-000-002-341.htm

FIELD INDICATORS OF HYDRIC SOILS

Criteria are given for:

- all soils
  - example: A2 - Histic Epipedon
- specific for sandy soils
  - example: S4 - Sandy Gleyed Matrix
- specific for fine-textures soils
  - example: F8 - Redox Depressions

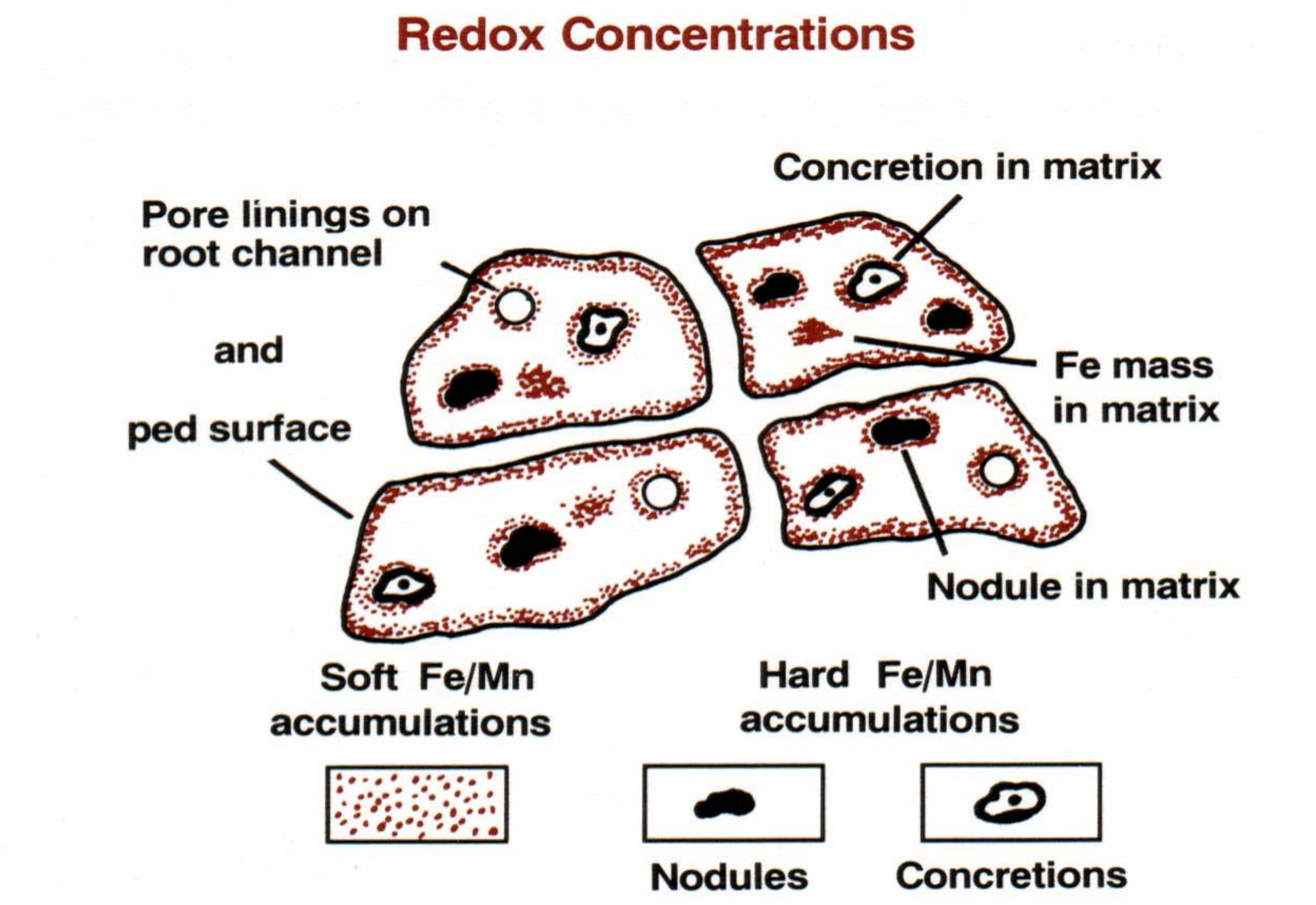
To document a hydric soil:

- remove all loose plant material from surface
- dig hole & describe profile to depth of 50 cm
- specify which Indicators have been matched

FIELD INDICATORS OF HYDRIC SOILS

Significantly different hydric soil morphologies exist in sands (left) than finer textured soils (right).

FIELD INDICATORS OF HYDRIC SOILS



Schematic illustration showing different kinds of redox concentrations and their relationship to soil macropores and matrices.

FIELD INDICATORS OF HYDRIC SOILS

Indicator F6 (Redox Dark Surface). The left is moist and the right is dry. Most commonly moist soil colors are used when identifying and delineating hydric soils.

FIELD INDICATORS OF HYDRIC SOILS

Indicator A3 (Black Histic). Proof of aquic conditions is not required.

FIELD INDICATORS OF HYDRIC SOILS

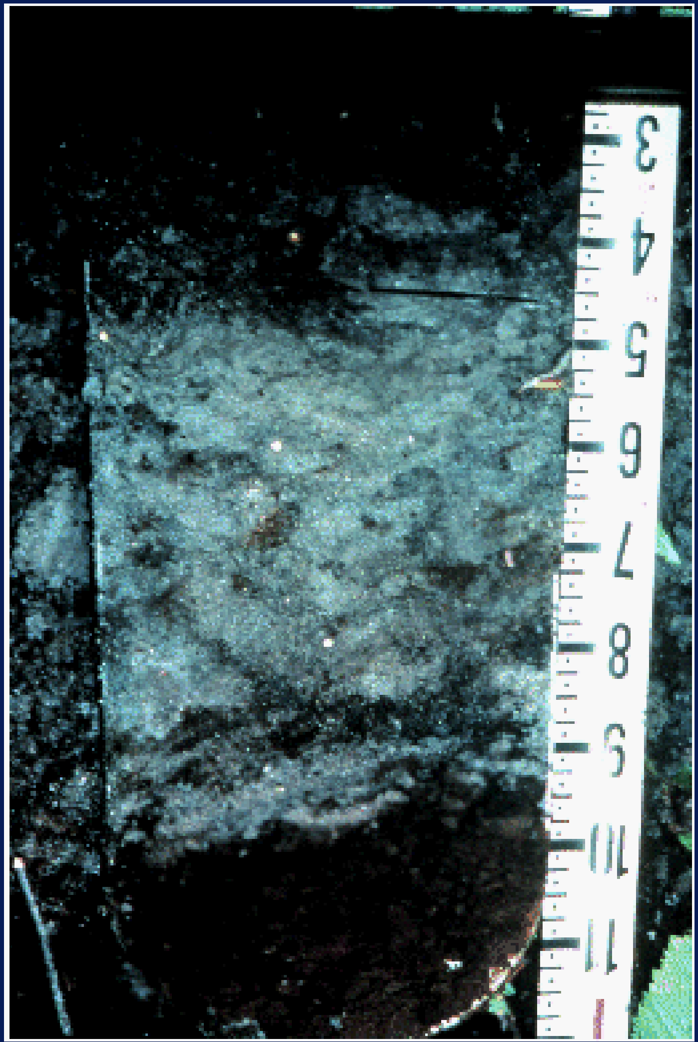
Indicator S5 (Sandy Redox) The redox masses occur below a depth of about 10 cm. (Scale is in inches).

FIELD INDICATORS OF HYDRIC SOILS

The gleyed matrix in this soil (Figure 19) begins at a depth of about 18 cm.

Indicator F3 (Depleted Matrix) also occurs in the E horizon between the gleyed matrix and the surface layer.

Redox concentrations are required in E horizons if they are recognized as meeting F3.



FIELD INDICATORS OF HYDRIC SOILS

If the chroma is 2 and value less than 6, redox concentrations are required as in this soil (Figure 20) where they occur below a depth of about 15 cm; scale is inches.

WETLANDS & THEIR POORLY AERATED SOILS

Hydrophytic vegetation:

- tolerate/thrive in wetland conditions
- characteristic of wetlands
- criteria for defining welands
- bald cypress, common cattail, fragmites grass, reed canarygrass, swamp white oak

Wetland chemistry:

- low O_2 except for surface oxidized zone
- nitrogen reduction to N_2
- redoximorphic features
- reduction of S to sulfides
- C, N, S, Cr, Se also affected

Constructed wetlands:

- wetland mitigation - difficult to construct what we don’t fully understand

PROCESSES AFFECTED BY SOIL TEMPERATURE

Plant processes:

- germination, vegetative growth, flowering
- optimal temp ranges for different species
- root functions; winter burn due to low uptake of water

Microbial processes:

- "biological zero" at about 5˚C
- rates gen. more than double for each 10˚C temp rise up to 35-40˚C
- can apply NH_3 during cold temps & NO_3^- won't form
- raise plant temps with sheeting to control fungal diseases
- high soil temps necessary for remedial processes

PROCESSES AFFECTED BY SOIL TEMPERATURE

Freezing & thawing:

- ice lenses may destroy soil structure
- frost heaving may lift structures & plants
  - fence posts, shallow foundations, roads
  - see FIGURE 7.25

Permafrost:

- about 25% of earth's land area are underlain by permafrost
- Alaska: temps at top of pemafrost have increased 3.5 ºC since the late 1980s.
- foundations, roadbeds, trees affected
- may be increased release of CO_2
- ice melting will cause soil instability

PROCESSES AFFECTED BY SOIL TEMPERATURE

Soil heating by fire:

- natural fires generally cause minimal increases in soil temperatures
- "slash & burn" practices may cause high soil temperatures
- may release hydrophobic compounds into soil, reducing water sorption capacity
- many seeds need fires to germinate
- burning stubble in cultivated fields kills most weed seeds

Contaminant removal:

- soil heating is sometimes used to remove organic contaminants
- is expensive and is one of "last resort" methods

ABSORPTION AND LOSS OF SOLAR ENERGY

Albedo:

- the fraction of incident radiation reflected by the earth's surface
- dark-colored, rough surfaces = 0.1-0.2
- light-colored, smooth surfaces = up to 0.5
- not all dark-colored soils are warmer; many are in low areas and are wetter, and cooler

Aspect:

- direction of soil slope
- angle at which sun's rays strike soil influence temp
- N-facing vs S-facing slope temperatures

ABSORPTION AND LOSS OF SOLAR ENERGY

Rain:

- warm spring rains may warm soil
- water evaporation cools soil

Soil cover:

- bare, mulch, snow, grass, forest
- grassed areas cooler due to transpiration
- forest soils cooler due to shading & transpiration
- partially logged areas maintain cooler soil temps

THERMAL PROPERTIES OF SOILS

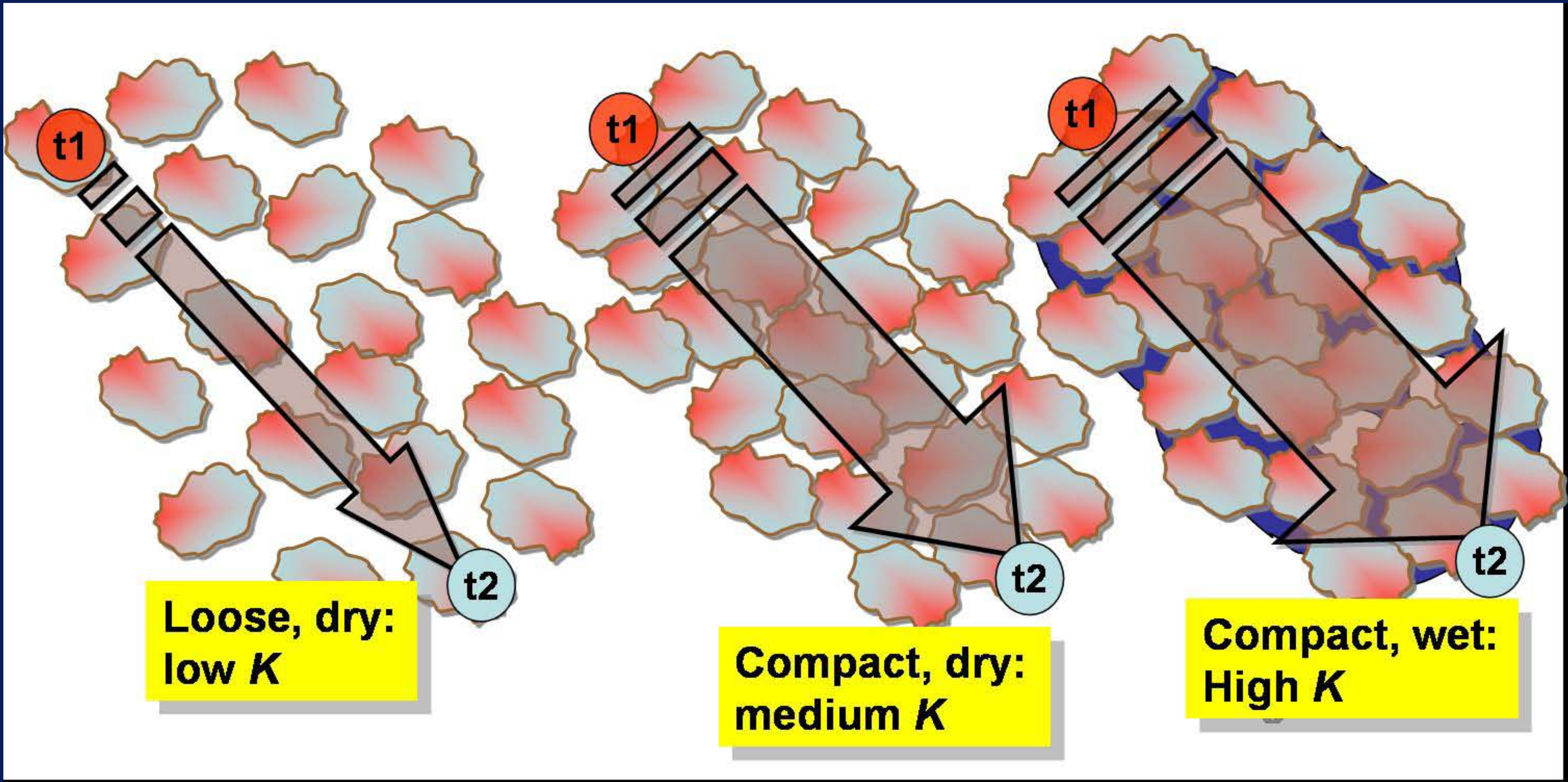
Specific heat of soils:

- specific heat is heat capacity per unit mass
- specific heat of H_2O = 1.00 cal/g
- specific heat of dry soil = 0.2 cal/g
- wet soils warm more slowly than drier ones

Heat of vaporization:

- evaporation of H_2O from soil requires 540 kcal
- potential to significantly cool soil
- low temp of wet soil due partially to evaporation and partially due to high specific heat
- a few degrees makes difference in seed germination or not

Effect of bulk density and water on heat transfer rate



THERMAL PROPERTIES OF SOILS

Thermal conductivity of soils:

- rate of heat flow determined by driving force and ease with which heat flows

$Q_h = K * (\Delta T/x)$

Q_h - thermal flux

K - thermal conductivity

$\Delta T/x$ - temp gradient over dist. *x* which serves as driving force

- wet, compacted soil has high heat transfer rate
- dry soil is a good insulating material

THERMAL PROPERTIES OF SOILS

Soil temperature fluctuations:

- regular, seasonal changes

Vertical & seasonal temperature changes:

- surface variations greatest
- subsurface variations least
- subsurface changes lag behind surface changes
- some temperature variation at 300 cm depth

Daily variations:

- air temperature max at about 2 PM
- soil temperature max at late afternoon
- little variation in lower subsoil

SOIL TEMPERATURE CONTROL

Organic mulches and plant-residue management:

- mulches effectively buffer extremes in soil temps
- forest floor is good example of natural mulch
- logging (clearing) of litter affects soil temp

Mulch from conservation tillage:

- leaves stubble in place to serve as mulch
- lowers soil temperatures

Concerns in cool climates:

- many areas stubble mulch lowers temps when not desired
- inhibition of seed germination, seedling growth
- especially effects midday maximum temperatures

SOIL TEMPERATURE CONTROL

Plastic mulches:

- generally increase soil temperature
    - clear plastic has greater effect than black
- can extend growing season - early or late
- may cause excessive heating in summer
    - must weigh temps vs weed control & moisture conservation

Moisture control:

- control soil temps by controlling soil moisture
    - drainage
    - soil ridges or mounds
- soil drainage to increase soil temperatures
- add moisture to cool soil

USE OF PLASTIC MULCH ON HIGH VALUE CROPS

No till sweet corn in PA, using biodegradable plastic

Winter-grown strawberries in Southern CA

(Figures 7.38 & 7.39)