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)
Gaseous composition of soil air:
- O₂: ~19% to <5% (atmos = 21%)
  - may be ~0% in waterlogged soils
- CO₂: 0.35% - 10% (atmos = 0.035%)
- Other gasses: H₂O vapor - nearly saturated
  H₂S, CH₄, C₂H₂

Air-filled porosity:
- >20% is best for microbial growth
- O₂ diffusion very slow in H₂O filled pores
- when low, H₂O fills pores & may have anaerobic conditions
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)
Redox reactions:

\[ 2\text{FeO} + 2\text{H}_2\text{O} \Leftrightarrow 2\text{FeOOH} + 2\text{H}^+ + 2\text{e}^- \]

- oxidizing agent: accepts electrons easily
- reducing agent: supplies electrons easily

Role of oxygen:

- strong oxidizing agent

\[ 0.5\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \Leftrightarrow \text{H}_2\text{O} \]
Combined reaction:

\[ 2\text{FeO} + 2\text{H}_2\text{O} \Leftrightarrow 2\text{FeOOH} + 2\text{H}^+ + 2\text{e}^- \]
\[ 0.5\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \Leftrightarrow \text{H}_2\text{O} \]
\[ 2\text{FeO} + 0.5\text{O}_2 + \text{H}_2\text{O} \Leftrightarrow 2\text{FeOOH} \]

Other electron acceptors:

\[ \text{NO}_3^- + 2\text{e}^- + 2\text{H}^+ \Leftrightarrow \text{NO}_2^- + \text{H}_2\text{O} \]

- if sufficient \( \text{NO}_3^- \) is present, \( \text{Eh} \) 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
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 formation

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, depletion 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 conditions
Effects on activities of higher plants:
- plant species vary widely in tolerance to low O₂
- differences in tolerance at different life stages
- low O₂ levels constrain root respiration, plant may wilt

Soil compaction & aeration:
- compaction does limit exchange of 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 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)
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 | Lobolly pine | Sycamore | Sugar beets | Walnut |
| Reed canary grass | Orchard grass | Weeping love grass | Walnut | Wheat |
| Rice | Redtop grass | Willow oak | White pine | |
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
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
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
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
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
Significantly different hydric soil morphologies exist in sands (left) than finer textured soils (right).
FIELD INDICATORS OF HYDRIC SOILS

Redox Concentrations

Pore linings on root channel
and ped surface

Concretion in matrix
Fe mass in matrix
Nodule in matrix

Soft Fe/Mn accumulations
Hard Fe/Mn accumulations

Schematic illustration showing different kinds of redox concentrations and their relationship to soil macropores and matrices.
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.
Indicator A3 (Black Histic). Proof of aquic conditions is not required.
Indicator S5 (Sandy Redox)
The redox masses occur below a depth of about 10 cm. (Scale is in inches).
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.
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.
Hydrophytic vegetation:
- tolerate/thrive in wetland conditions
- characteristic of wetlands
- criteria for defining wetlands
- 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
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 NH₃ during cold temps & NO₃⁻ won’t form
- raise plant temps with sheeting to control fungal diseases
- high soil temps necessary for remedial processes
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 °C since the late 1980s.
- foundations, roadbeds, trees affected
- may be increased release of CO₂
- ice melting will cause soil instability
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
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
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 H₂O = 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 H₂O 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

Loose, dry: low $K$

Compact, dry: medium $K$

Compact, wet: High $K$
Thermal conductivity of soils:
- rate of heat flow determined by driving force and ease with which heat flows

\[ Q_h = K \times (\Delta T/x) \]

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

Winter-grown strawberries in Southern CA

No till sweet corn in PA, using biodegradable plastic

(Figures 7.38 & 7.39)