# SOIL AERATION AND TEMPERATURE

# INTRODUCTION – SOIL AERATION

**Air and water share the pore space in soils, therefore...**

- Texture of soil
- Structure of soil
- Porosity of soil
- Retention of water by soil
- Movement of water in soil

**...all have a direct bearing on the aeration of soil**

# PROCESS OF AERATION

***Aeration:*** **ventilation of soil, with gases moving into and out of the soil**

## Aeration controls:

- Rate of gas exchange with atmosphere
- Proportion of pore spaces filled with air
- Composition of soil air
- Oxidation-reduction potential of soil environment

# OXYGEN AVAILABILITY IN FIELD SOILS

## Oxygen availability regulated by:

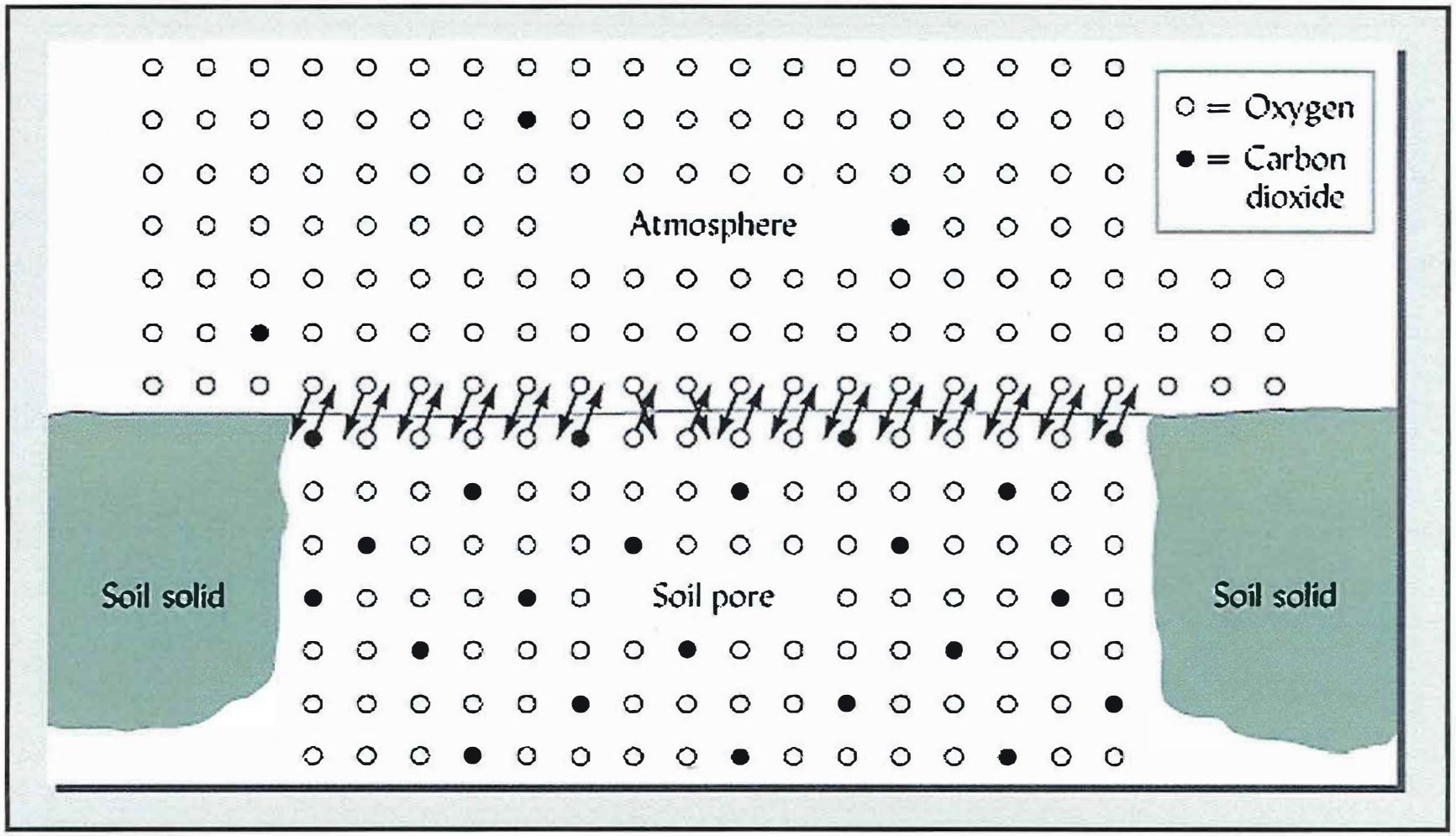
1) Soil macro porosity
   - Affected by texture and structure
2) Soil water content
   - Affects proportion of porosity filled by air
3) Oxygen consumption
   - Respiration of plant roots and microorganisms

# MECHANISMS OF GAS EXCHANGE

**Air enters soil by two major mechanisms which generally replenish $O_2$ in soil and flush $CO_2$ from soil**

1. Diffusion across soil surfaces
   - Movement from zones of higher to lower concentrations
   - Due to random movement of molecules
   - Very dependent on physical condition of surface

# DIFFUSION BETWEEN GASES IN A SOIL PORE AND THE ATMOSPHERE



## MECHANISMS OF GAS EXCHANGE

2. Mass flow due to physical disturbance
   - Water movement into soil displaces air
   - Water movement out of soil (evaporation) pulls air into soil
   - Tillage introduces new air

FACT: Well ventilated soil will exchange gases rapidly enough to prevent *oxygen deficiency* or *carbon dioxide toxicity*

# CHARACTERIZING SOIL AERATION

## Gaseous content of soil atmosphere

- Higher $O_2$ in atmosphere, lower in soil
- Lower $CO_2$ in atmosphere, higher in soil
- >78% N in atmosphere, approx. 78% in soil

## Air filled porosity

- Microbiological and plant growth restricted when air filled porosity drops below 20 percent
- Increasing water content slows diffusion rate

# CHARACTERIZING SOIL AERATION

## Oxidation-Reduction Potential

- Also called Redox Potential ($E_h$)
- A measure of the tendency of a substance to donate or accept electrons
- A substance which donates electrons is known as a *reducing agent*
- A substance which accepts electrons is known as an *oxidizing agent*
- Microbes responsible for much redox activity in soils thru respiration

# CHARACTERIZING SOIL AERATION

## Oxidation-Reduction Potential (cont)

- Oxygen gas ($O_2$) is a strong oxidizing agent
  - Accepts electrons from many elements
  - Can oxidize both organic and inorganic substances
  - All aerobic respiration requires oxygen as electron acceptor to oxidize organic carbon (for energy)
  - Oxygen ($O_2$) is reduced as it oxidizes other substances

# CHARACTERIZING SOIL AERATION

## Oxidation-Reduction Potential (cont)

- High, positive $E_h$ provides favorable environment for oxidation
  - Generally correlated with $O_2$ concentration in soils
  - Predominance of oxidized forms in well aerated soils
  - Oxidized forms = $O_2$, $NO^{3-}$, $Mn^{4+}$, $Fe^{3+}$, $CO_2$
  - Oxidizing conditions: predominance of red soil colors due to $Fe^{3+}$

# CHARACTERIZING SOIL AERATION

## Oxidation-Reduction Potential (cont)

- Low $E_h$ provides favorable environment for reduction
  - Waterlogging reduces $O_2$, therefore lowers $E_h$
  - Predominance of reduced forms in waterlogged soils
  - Reduced forms = $H_2O$, $N_2$, $Mn^{2+}$, $Fe^{2+}$, $CH_4$
  - Reducing conditions: predominance of yellows, grays, blue colors in soils due to $Fe^{2+}$ and $Mn^{2+}$

# EFFECT OF SOIL AERATION ON PLANTS

## Plants affected in 3 ways by poor aeration

1) Root growth is slowed or curtailed
   - Different species vary in their tolerance of poor aeration

2) Absorption of nutrients and water decreased
   - Excess available water in soil can reduce uptake of water (by constraining root respiration)
   - Plants may exhibit nutrient deficiency on poorly drained soils even though nutrients are in good supply

3) Formation of toxic inorganic compounds favored under poor aeration

Sugar beets dying from lack of oxygen in compacted area

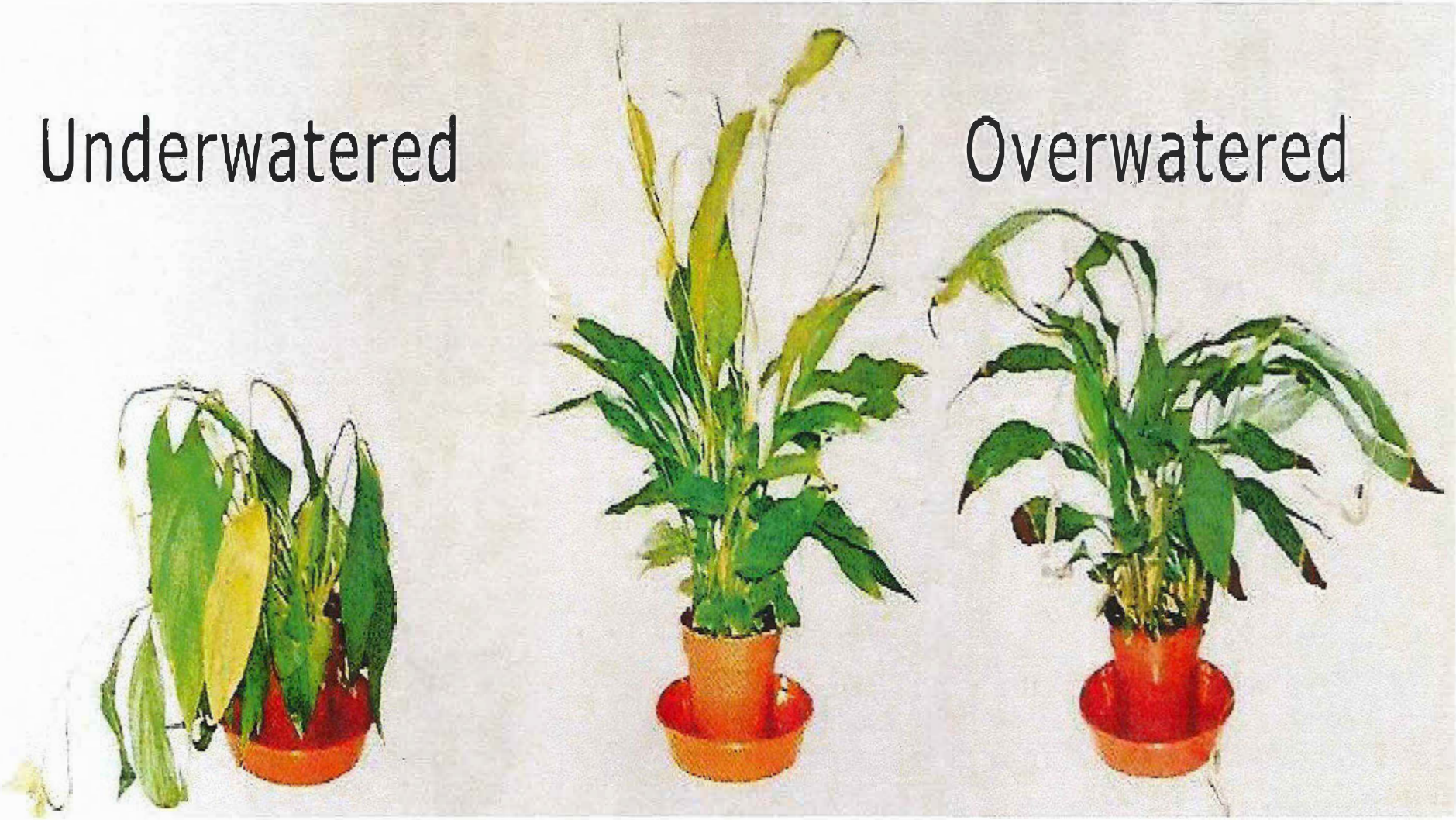
Pine trees dying in sandy soil recently flooded

# SOIL AERATION AND PLANT MANAGEMENT

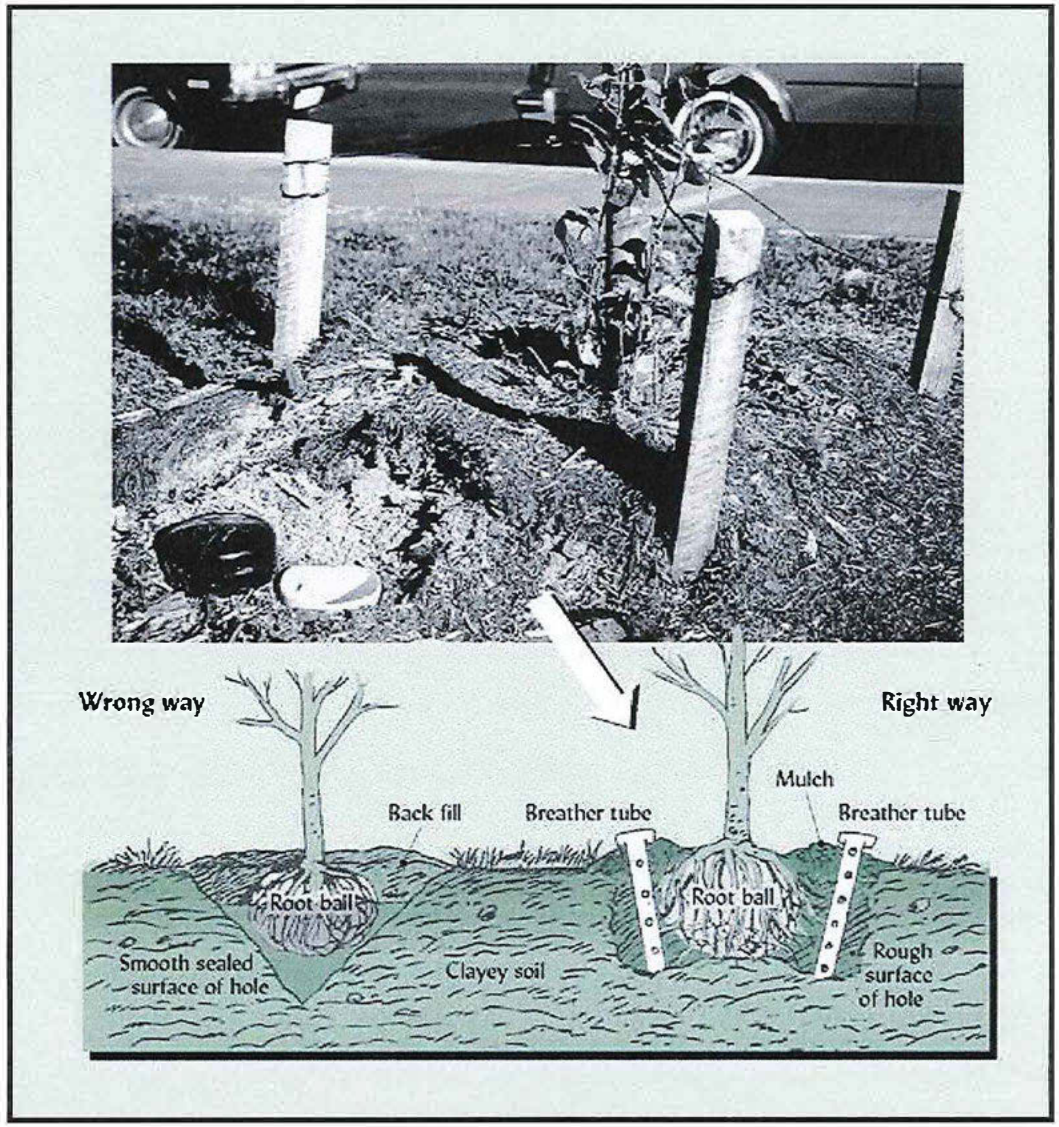
## Overwatering most common problem for irrigated or containerized plants

- Waterlogging leads to poor aeration

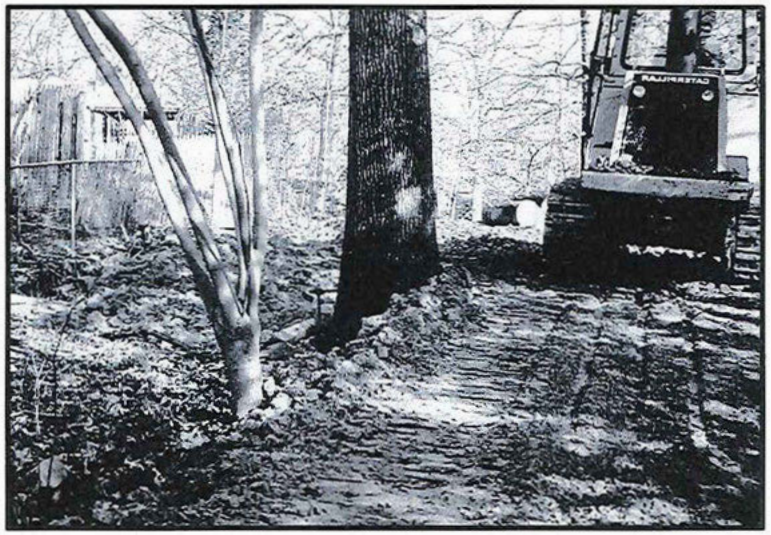
- Need to maintain structure to promote good aeration
  - Potting mixes for container plants
  - Adding residue, no till systems in fields
  - Core cultivators, earthworms etc. in lawns


Underwatered
Overwatered

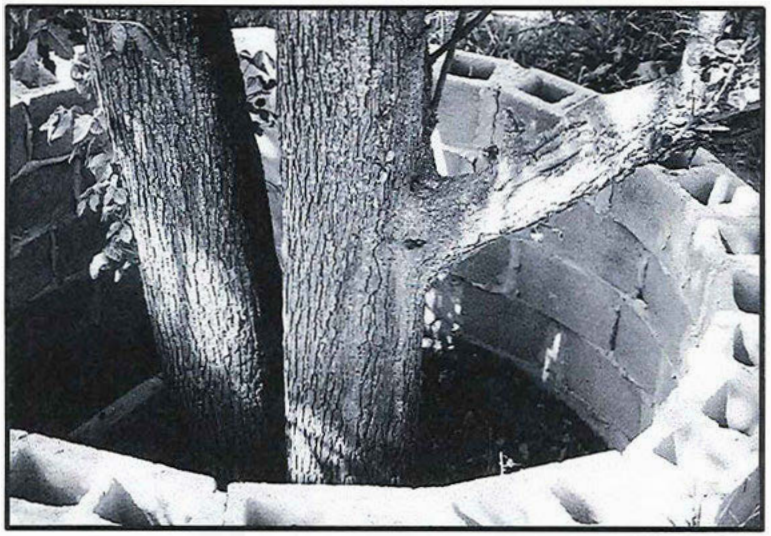
# IMPROVING AERATION TO ROOT ZONE OF TRANSPLANTED TREE



# PROTECTION OF TREES DURING GRADING OPERATIONS

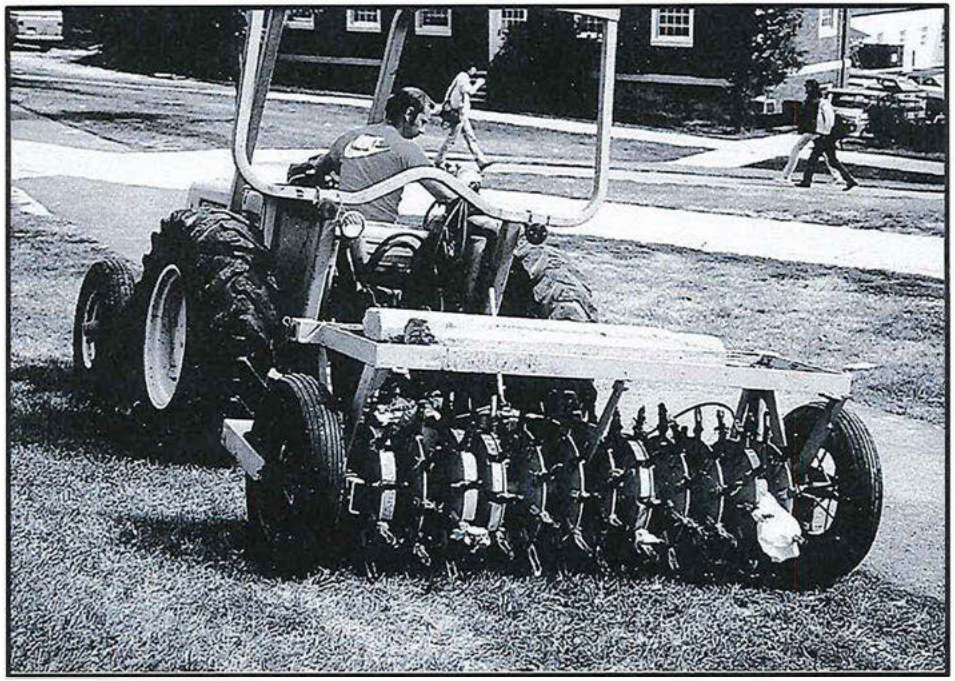


A thin layer of soil can suffocate tree roots



A dry well preserving original ground surface so roots can obtain sufficient oxygen

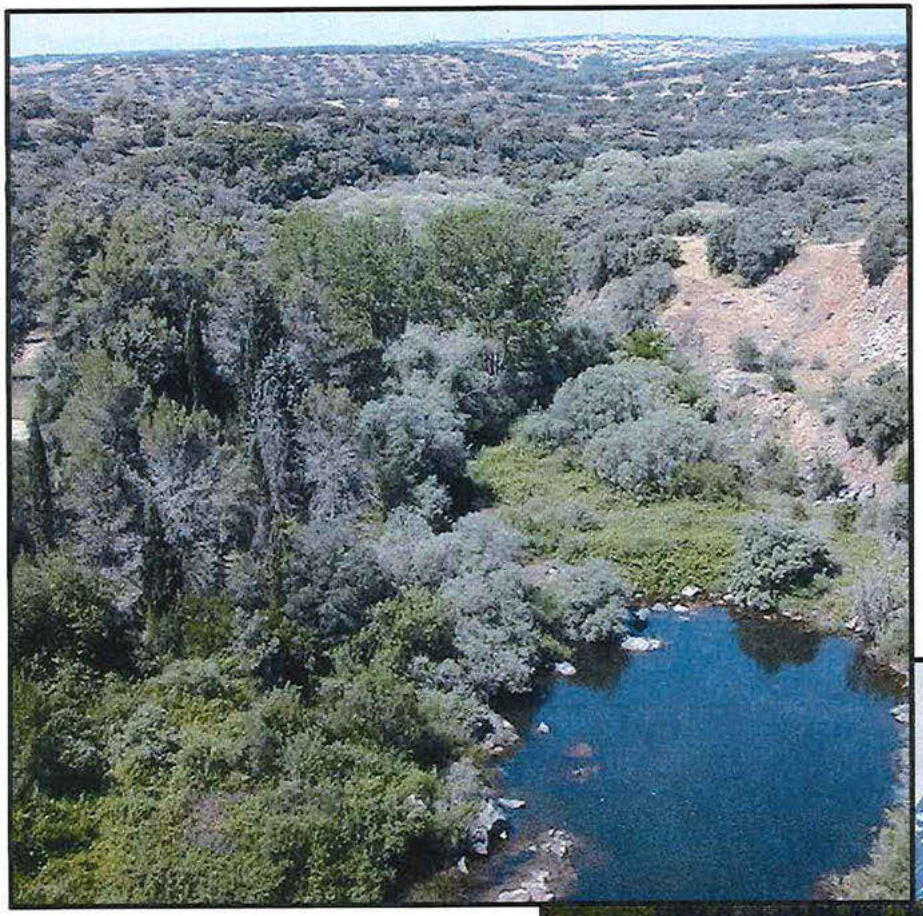
# CORE CULTIVATION FOR HIGH TRAFFIC AREAS

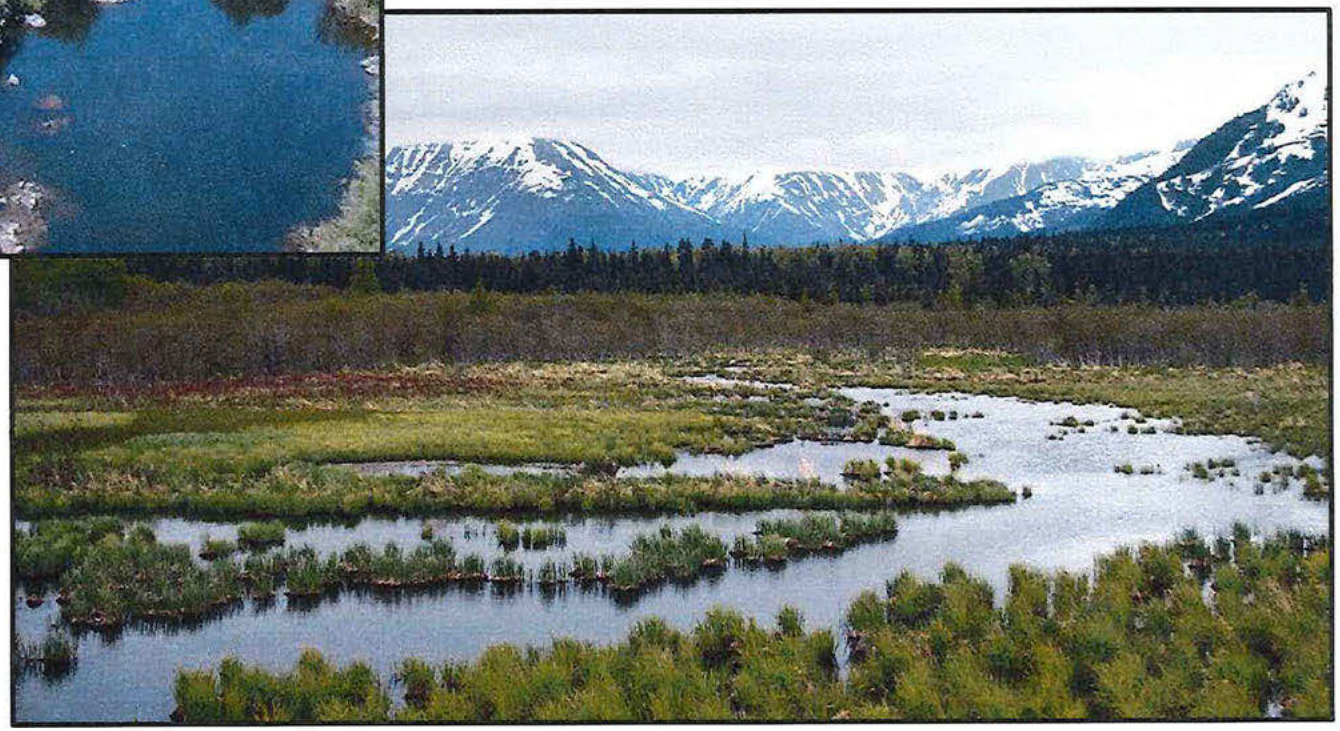


# WETLANDS

## *Wetland:* ecosystem that is transitional between land and water

- *Defined by* "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 the soil oxygen thereby assuring anaerobic conditions"





# WETLANDS

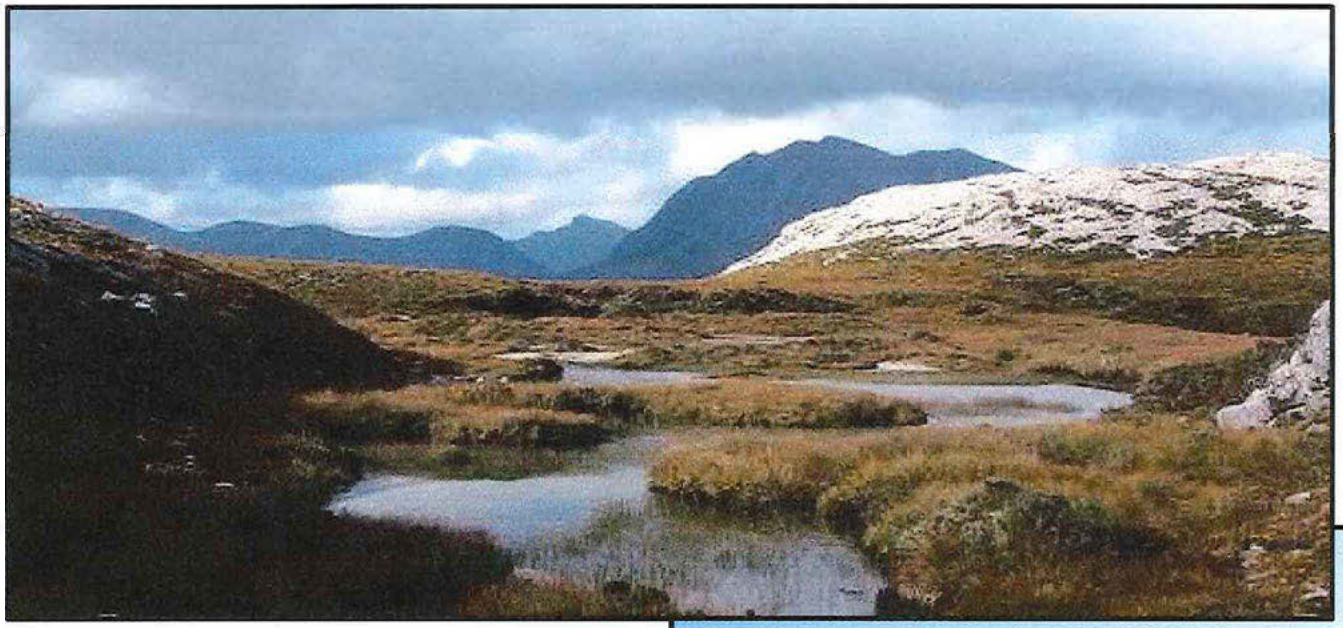
## To be a wetland need to meet three criteria:

1. Wetland hydrology or water regime
   - Area needs to be saturated for long enough in the year to develop hydric soils

2. Hydric soils (usually Histosols)
   - Subject to periods of saturation inhibiting the diffusion of $O_2$ into the soil
   - Undergo reduced conditions, (electron acceptors other than $O_2$ are reduced)
   - Exhibit hydric soil indicators in upper 50 cm

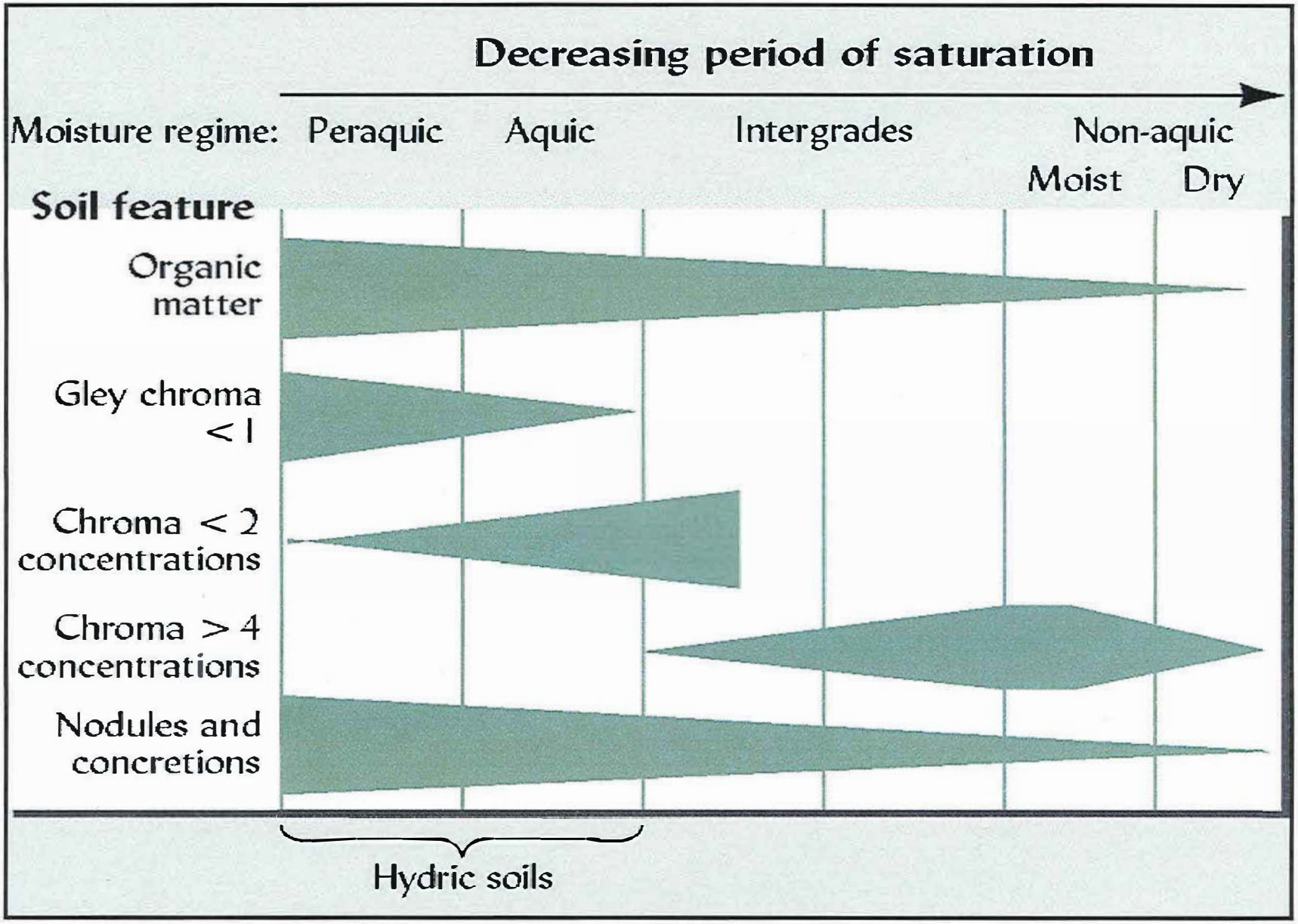
# WETLANDS

3. Hydrophytic vegetation (hydrophytes)
   - Plants which have specialized mechanisms allowing them to live in saturated anaerobic soils
   - Adaptive features may include:
     - Hollow *aerenchyma* tissues to transport $O_2$ to roots, floating leaves, inflated stems
     - Adventitious roots, knees, buttress roots, fluted trunks
     - Roots spread in shallow mass just under soil surface where some oxygen can diffuse

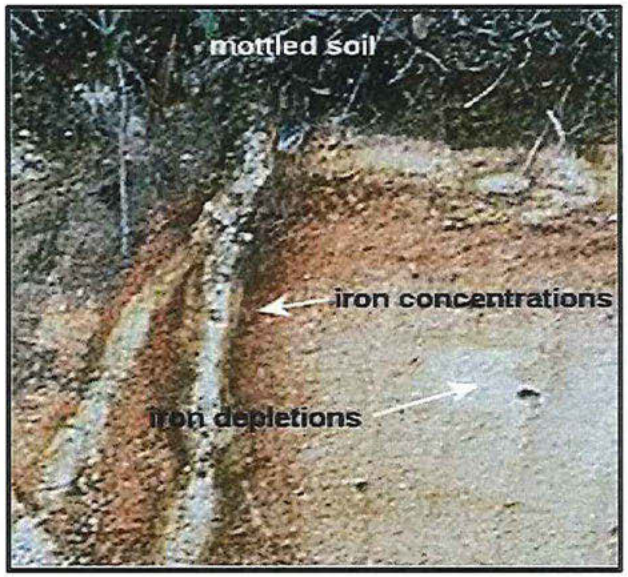


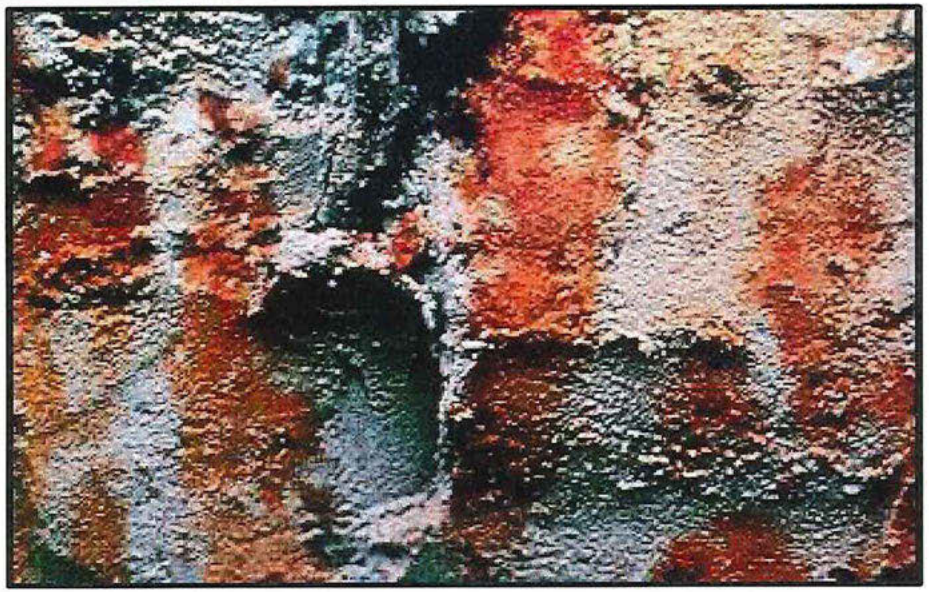
# WETLAND HYDROLOGY

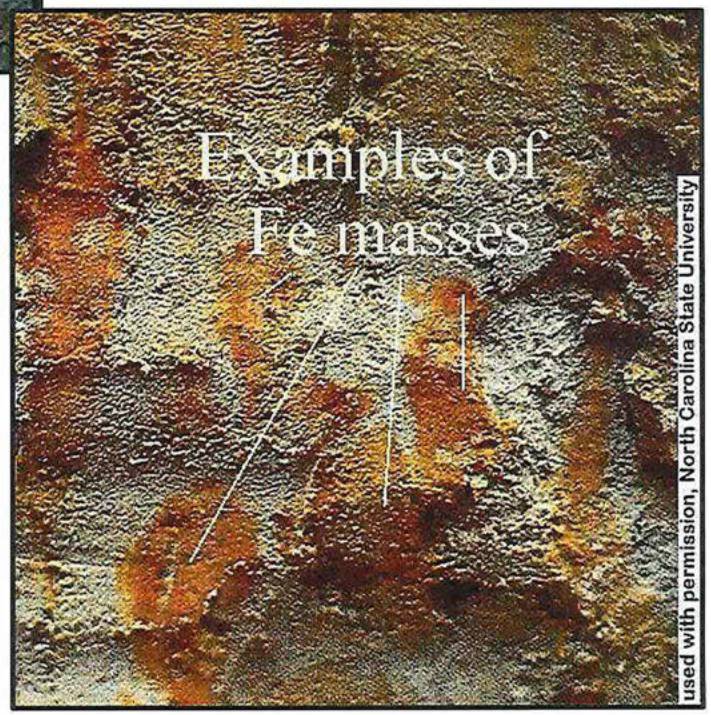
# HYDRIC SOIL INDICATORS



# REDOXIMORPHIC FEATURES





# PLANTS WITH VARYING DEGREES OF TOLERANCE TO WETNESS

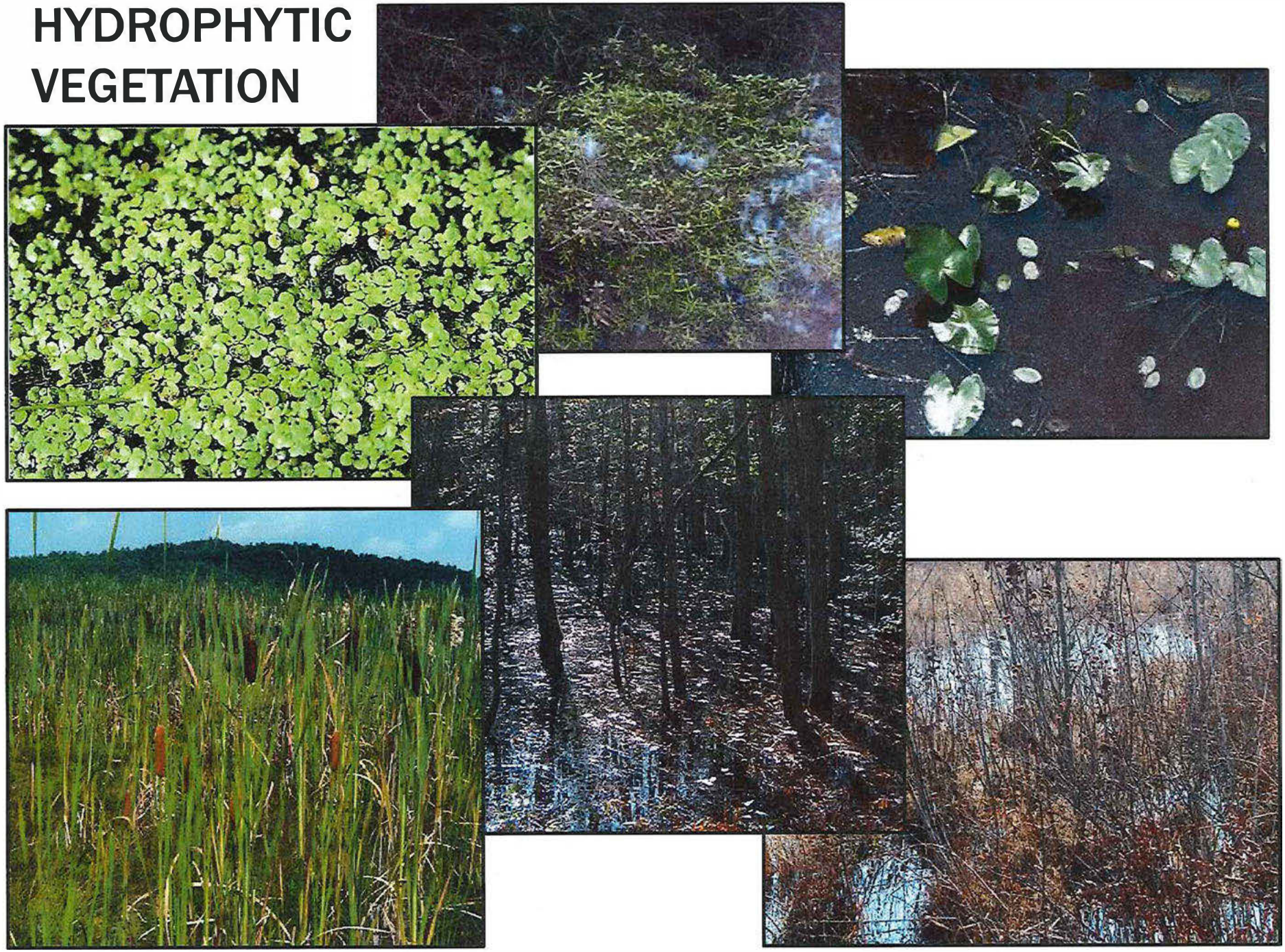
*The plants in the leftmost column commonly thrive in wetlands. Those in the rightmost column are very sensitive to poor aeration.*

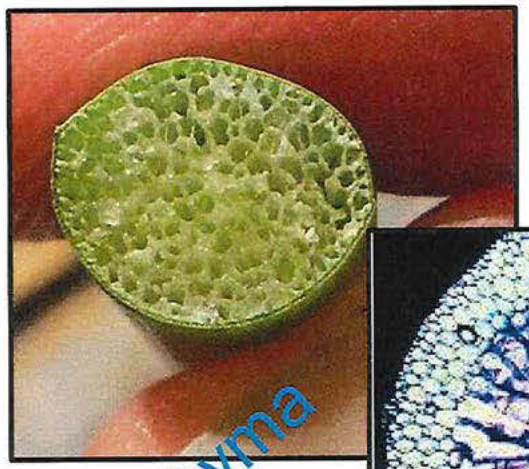
*Plants adapted to grow well with a water table at the stated depth*

| *<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 | Black Willow | Black locust | Birch | Barley |
| Common cattail | Cottonwood | Bluegrass | Cabbage | Beans |
| Cranberries | Deer tongue | Linden | Corn | Cherry |
| Duckgrass | Eastern gama grass | Mulberry | Hairy vetch | Hemlock |
| Fragmites grass | Ladino clover | Mustard | Millet | Oats |
| Maiden cane | Loblolly pine | Red maple | Peas | Peach |
| Mangrove | Orchard grass | Sorghum | Red oak | Sand lovegrass |
| Pitcher plant | Redtop grass | Sycamore | | Sugar beets |
| Reed canarygrass | Tall fescue | Weeping lovegrass | | Walnut |
| Rice | | Willow oak | | Wheat |
| Skunk cabbage | | | | White pine |
| Spartina grass | | | | |
| Swamp white oak | | | | |
| Swamp rosemalow | | | | |
| Water tupelo | | | | |

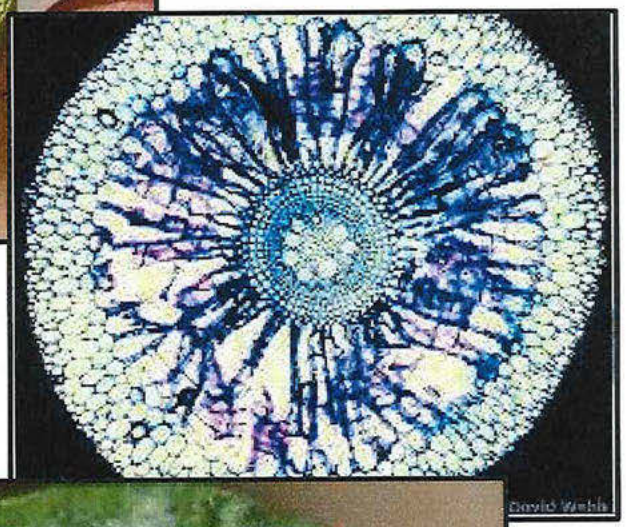
HYDROPHYTES

# HYDROPHYTIC VEGETATION





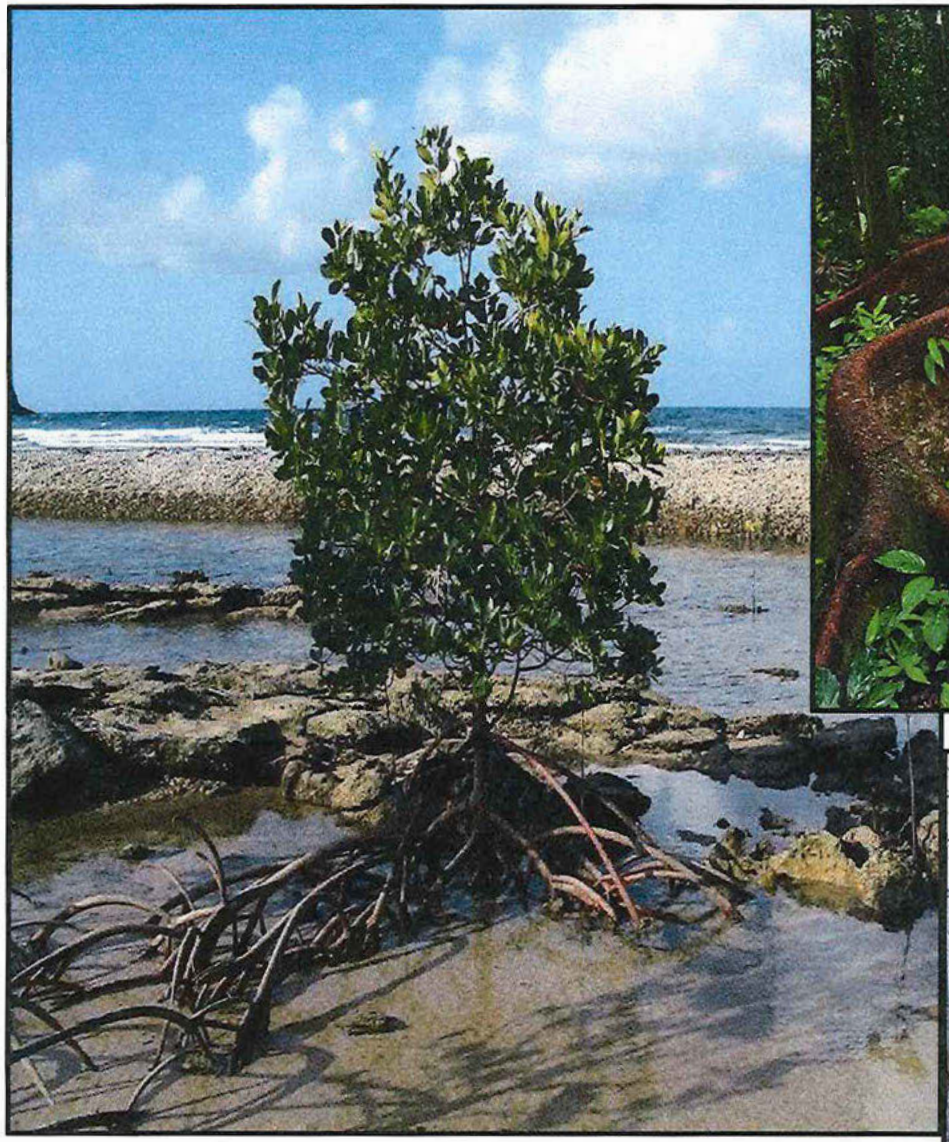
Arenchyma tissues



Adventitious roots


Floating leaves

Inflated stems (water hyacinth)



Buttressed and fluted trunks

# WETLANDS

## Benefits include:

- Species Habitat – 40% of T&E species, 1/3 of all US bird species
- Water filtration – remove sediment and N and P (eutrophication)
- Flooding reduction
- Shoreline protection
- Commercial and recreational activities
- Natural products

# INTRODUCTION – SOIL TEMPERATURE

- Soil temperature affects plant and microorganism growth
- Soil temperatures influence evaporation
- Increasing soil temperature influences soil aeration by:
  - Increasing rates of biochemical reactions
  - Stimulating growth of plants and organisms

# INTRODUCTION - SOIL TEMPERATURE

## Temperature important to physical, chemical, biological processes in soil

- Cold soils have decreased rates of chemical and biological activity
  - limits nutrient uptake
- Plants have narrow range of temperatures under which they will grow -- different for different species

# PROCESSES AFFECTED BY SOIL TEMPERATURE

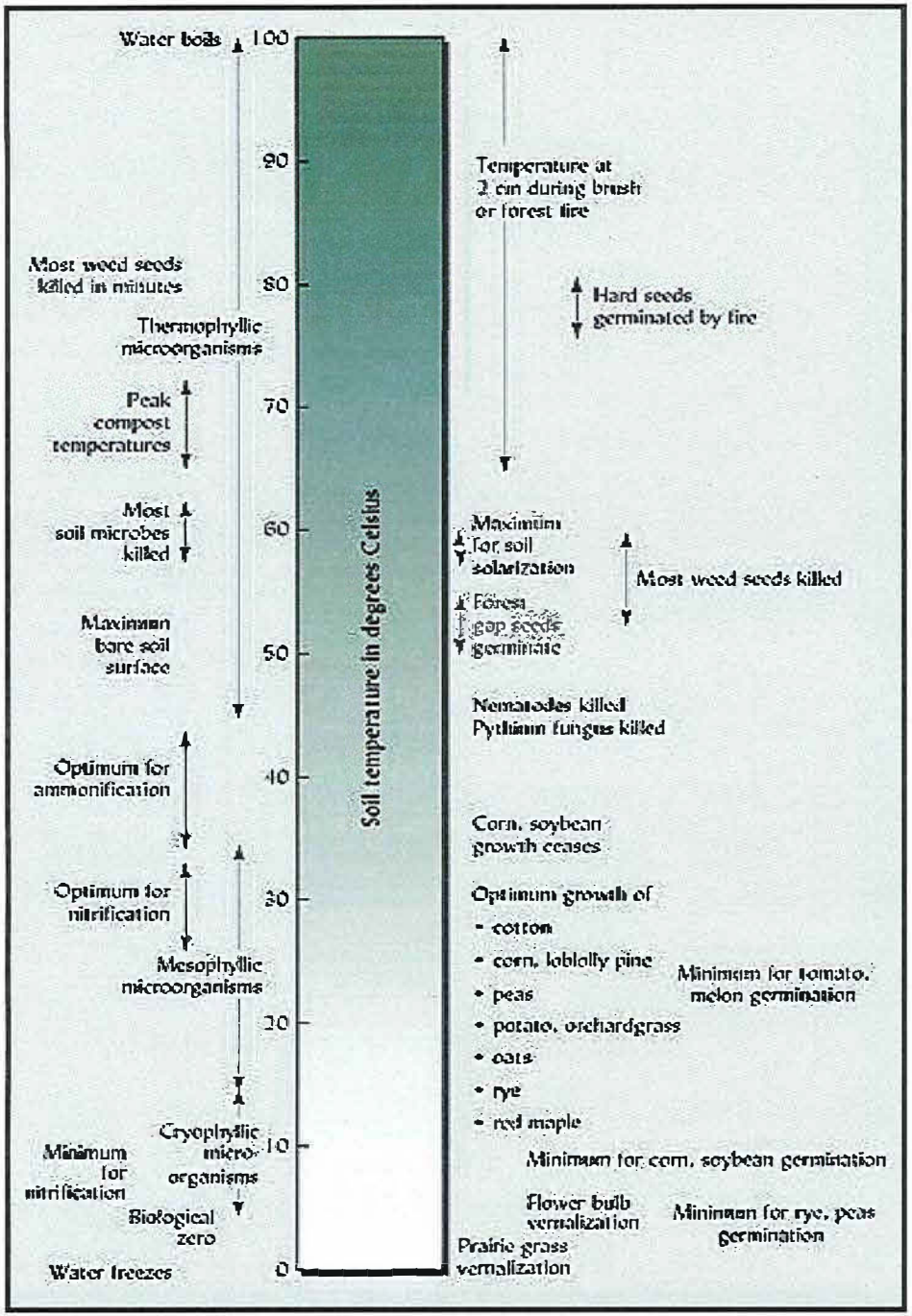
## Plant processes

- Plant growth generally more affected by soil temperature than air temperature
  - Narrow range of soil temperatures for optimum growth
- Seed germination
  - Different seeds, different optimal temperatures
- Root functions
  - Nutrient & water uptake affected by temperature

# PROCESSES AFFECTED BY SOIL TEMPERATURE

## Microbial processes

- Soil microbial activity and organic matter decomposition (usually) cease below 5 degrees C
- High soil temperatures can be used to control some plant diseases
- Microbial oxidation of ammonium to nitrate increases with increasing soil temperatures
- Microbial destruction of toxins requires warm soils




# SOIL TEMPERATURE RANGES ASSOCIATED WITH VARIOUS SOIL PROCESSES

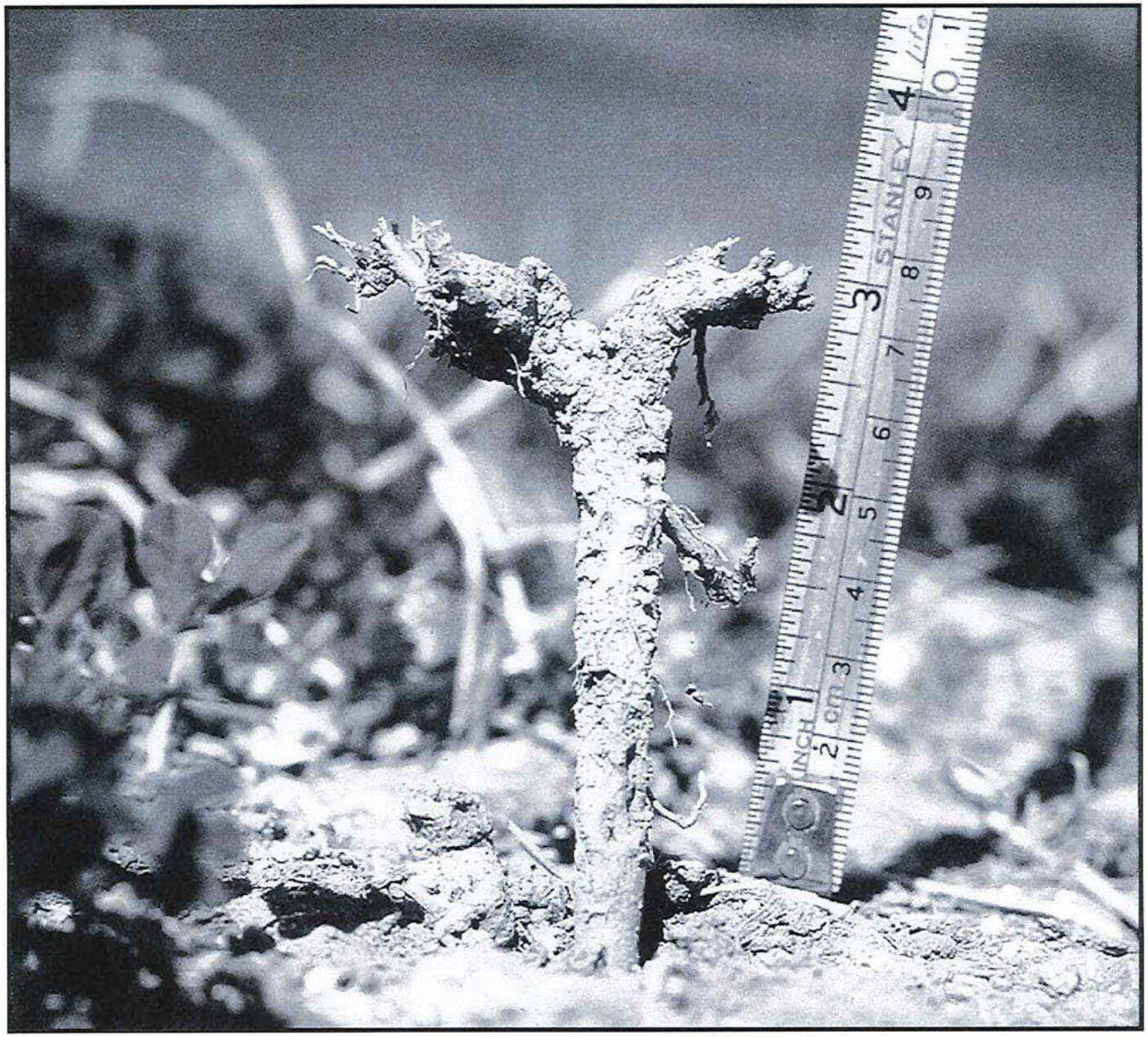
# PROCESSES AFFECTED BY SOIL TEMPERATURE

## Freezing and Thawing

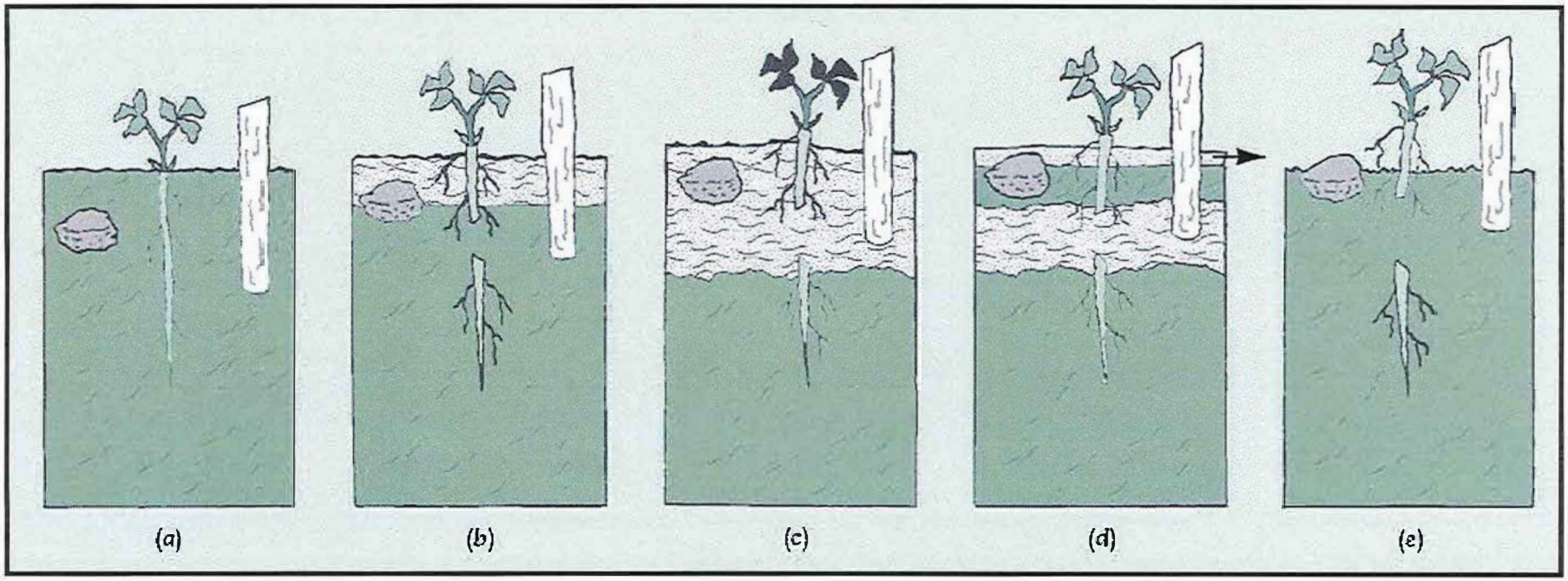
- Ice lenses form in soil causing pressure on soil aggregates
- Pressure can force objects upwards in a process called *frost heaving*
- Frost heaving can damage roads, foundations, etc
- More prevalent in soils with significant fine particles

# Frost-heaved foundation and road

Alfalfa root "jacked" out of ground



# HOW FROST HEAVING MOVES OBJECTS UPWARD




(a) Soil not frozen

(b) Ice lens forms, frozen soil tightens around object and lifts it

(c) Objects continue to be lifted as ice lens formation continues

(d) Soil surface subsides as thawing commences, object held in place by frozen material underneath

# PROCESSES AFFECTED BY SOIL TEMPERATURE

## Permafrost

- Soil permanently frozen at some depth

## Soil heating by fire

- Causes *hydrophobic* (water repellant) soils
  - Potential damage from erosion as infiltration is reduced
- May kill or affect germination of certain seeds
- May deplete organic matter (hot & long fire)

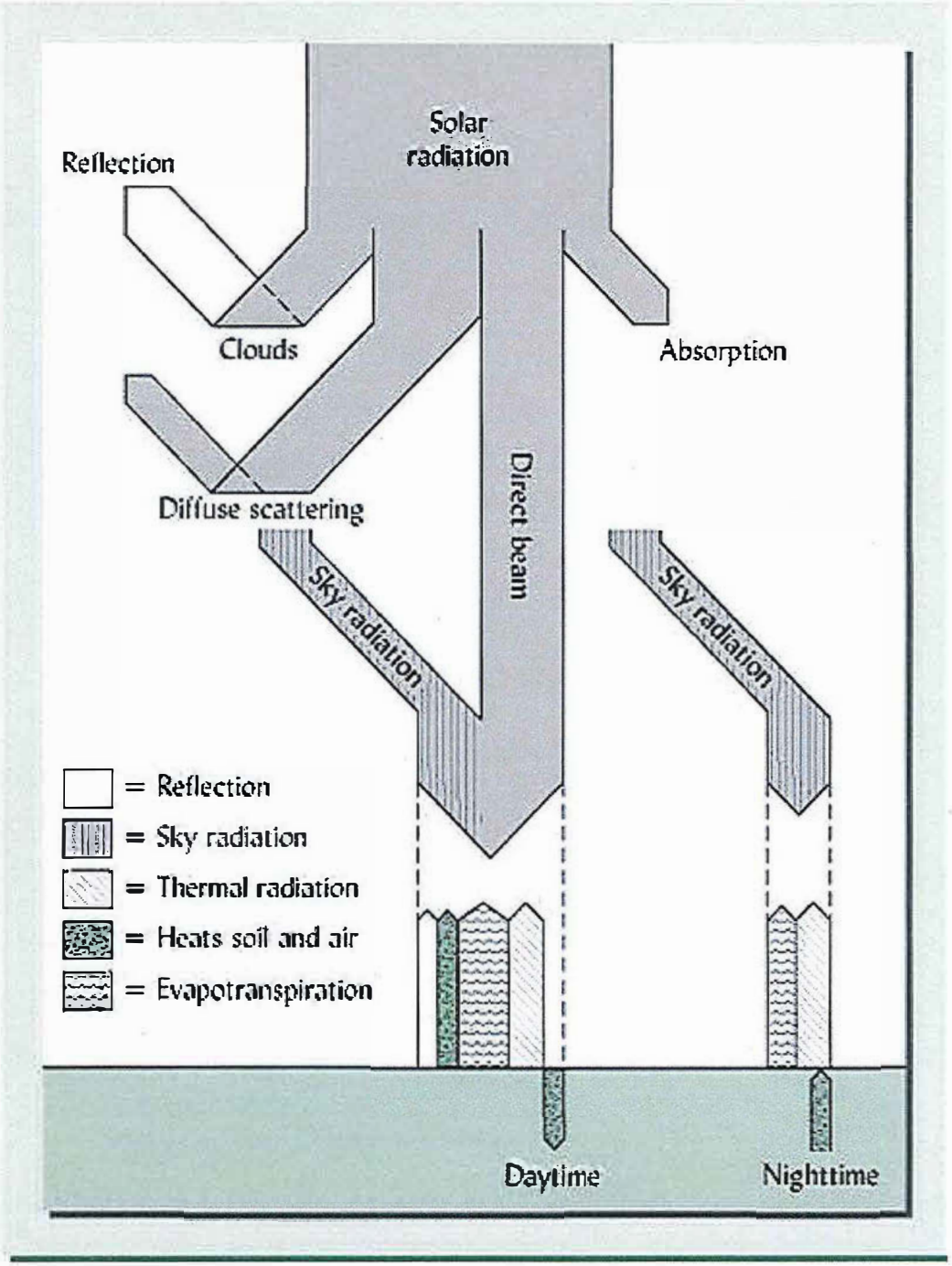
# ABSORPTION AND LOSS OF SOLAR ENERGY

## Soil is heated mainly by *solar radiation*

## Fates of solar radiation (35-70% reaches ground)

- reflected by atmosphere (clouds, dust)
- absorbed by atmosphere (clouds, dust)
- reflected by surfaces (plants, buildings)
- absorbed by surfaces (buildings, leaves)
- reflected by soils (and re-reflected by clouds)
- absorbed by soil

# Fates of Solar Radiation



# ABSORPTION AND LOSS OF SOLAR ENERGY

## Solar radiation absorbed by soils

- most used for evaporation of water
- some re-radiated (helps warm atmosphere)
- 10% that actually reaches soil helps warm it

## Heat energy is required to bring about any change in soil temperature

# SOIL TEMPERATURE

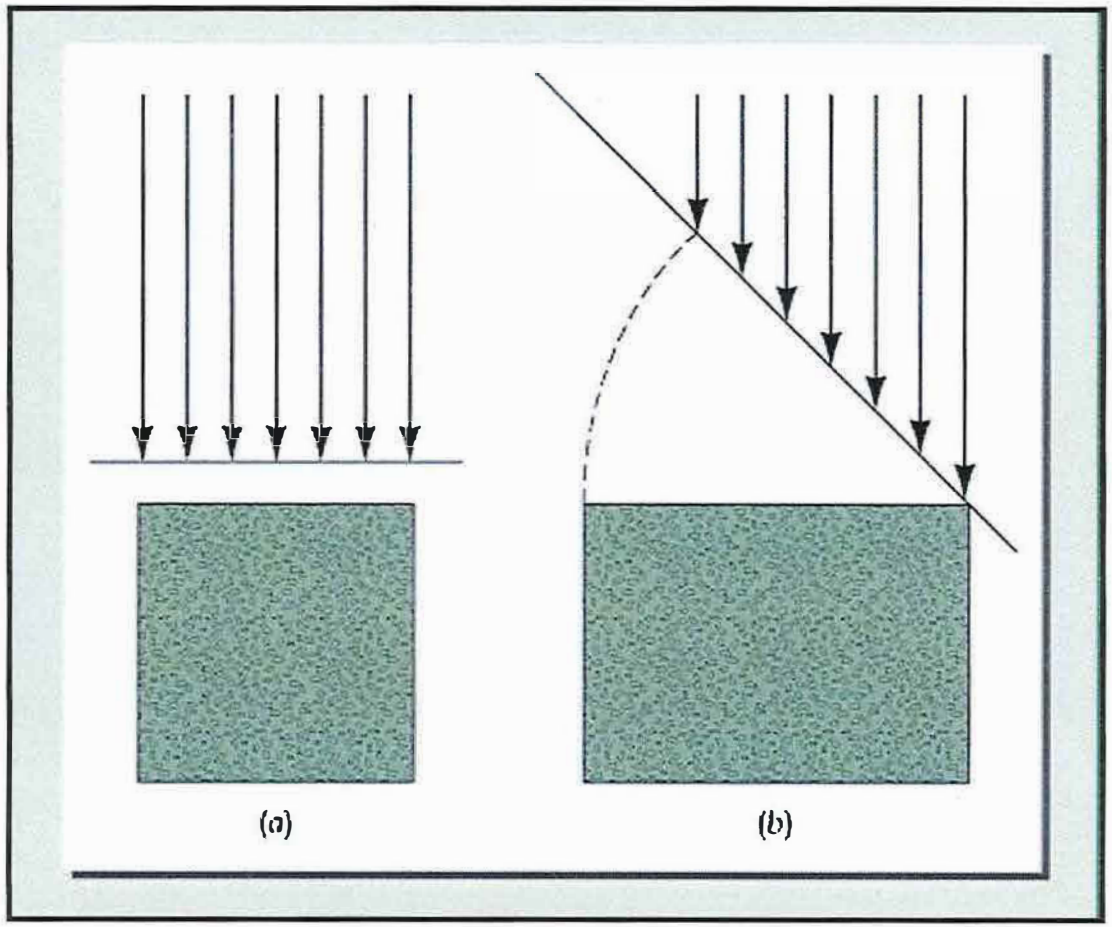
## Other factors influence amount of energy absorbed by soils, determine *rate of heating*

- Soil color: dark soils absorb more energy than light colored soils
  - dark soils may be cooler if they have more OM, are wetter, or both
- Soil moisture: water requires more energy to heat
  - wetter soils will tend to warm more slowly than dry soils

# SOIL TEMPERATURE

- Slope aspect: North slopes are cooler, south slopes are warmer (**in Northern Hemisphere**)
  - function of angle at which suns rays strike

Radiation concentrated on small area, soil warms quickly. South slopes warmer and drier than north slopes.




Same radiation as (a) but over 40% larger area, soil warms more slowly. North slopes cooler than south slopes.

# SOIL TEMPERATURE

- Soil cover:
  - Bare soils warm quickly and cool quickly as compared to soils with vegetative mulch cover
  - Plastic mulch can warm soil faster than if bare, but may cause excessive heat in soil, poor germination etc.

# SOIL TEMPERATURE

## *Rate of cooling* dependent on:

- Air temperature
- Wetness of soil
  - energy used for evaporation not warming
- Soil cover

## SOIL TEMPERATURE

**Once heat energy is in the soil it is transferred to other parts of the soil profile by <u>conduction</u>**

- similar to iron pipe with one end in fire, heat is transferred the length of the pipe

- rate of conduction controlled by moisture
  - higher moisture = better conduction
  - heat transfer easier between soil and water than soil and air

# SOIL TEMPERATURE

## Soils can be heated or cooled by rainfall

- "warm" rain on cool soils in spring
- "cool" rain on warm soils in summer

## Soils heat and cool from the top down

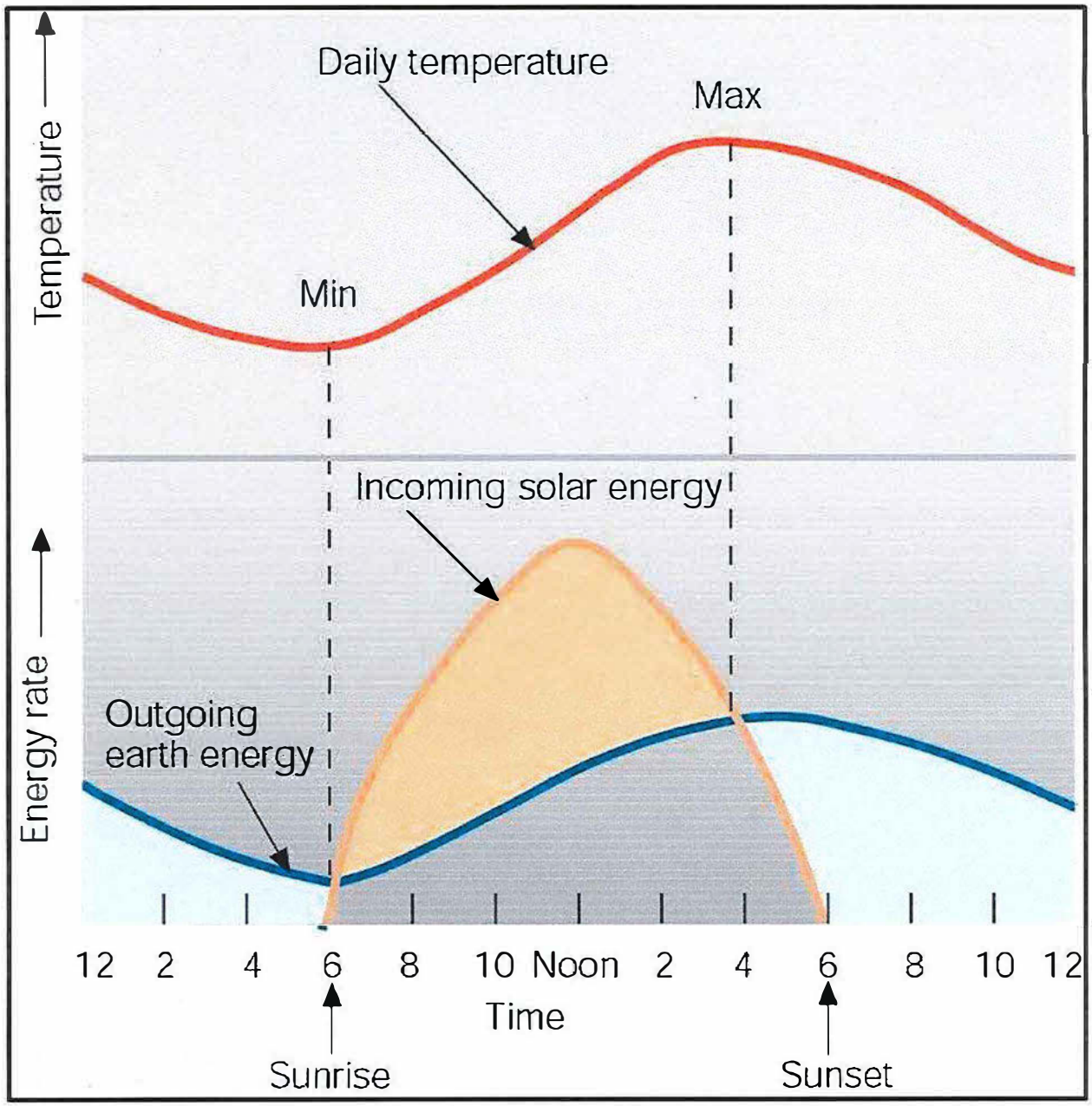
- there is a time lag in temperature across profile

# SOIL TEMPERATURE

## Soil temperature follow cycles

- Diurnal: warms during the day and cools at night
- Seasonal: warms in spring and cools later in the year

# DIURNAL (DAILY) SOIL TEMPERATURE AND SOLAR ENERGY RELATIONSHIPS

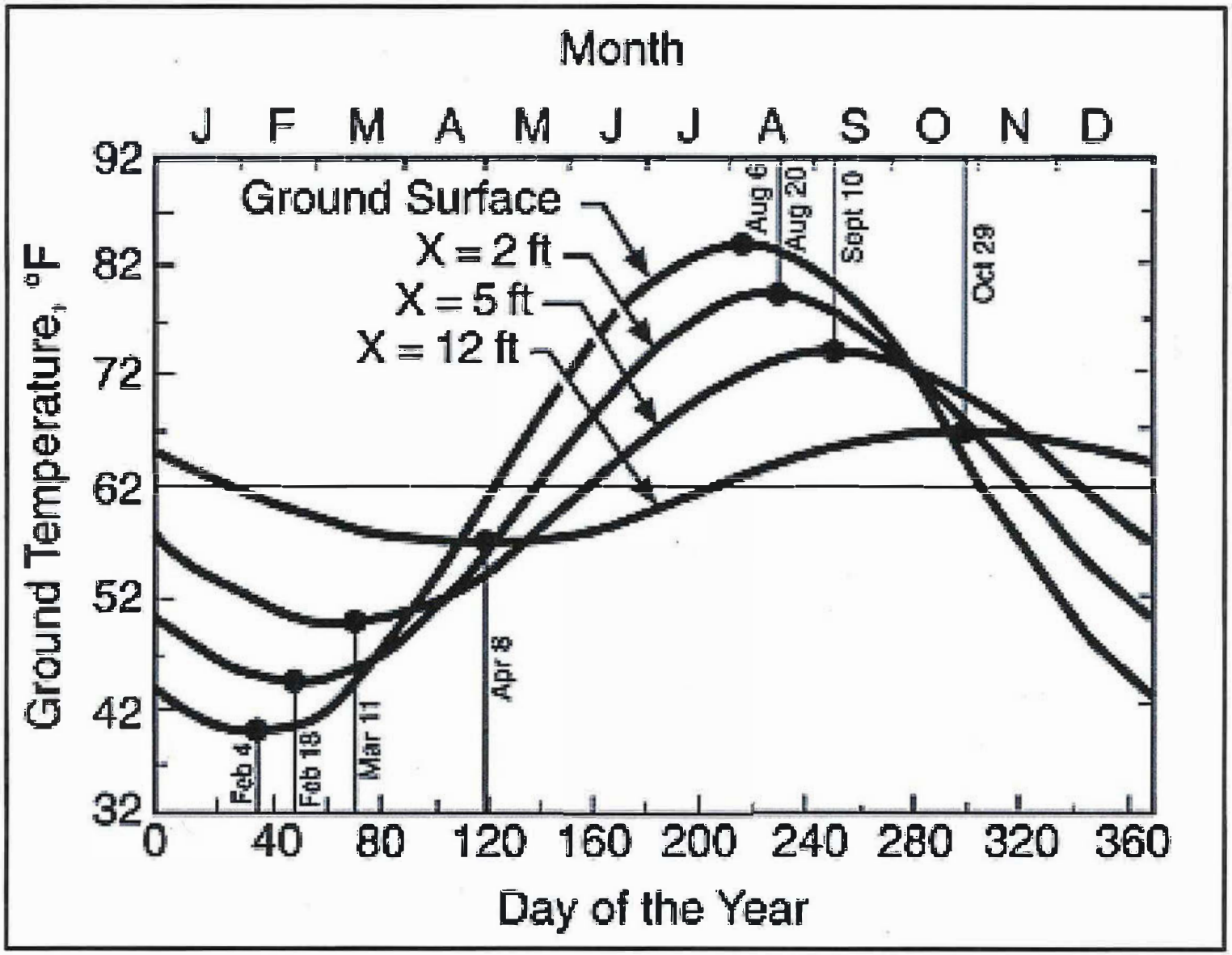


# SOIL TEMPERATURE

## Soil temperature not always directly synchronized with energy input

- surface soils warmest in late afternoon
- changes in subsoil temperatures lag behind surface soils
- magnitude of change less with increased depth
- subsoil generally warmer in winter and cooler in summer as compared to surface layers

# SEASONAL SOIL TEMPERATURE BY DEPTH



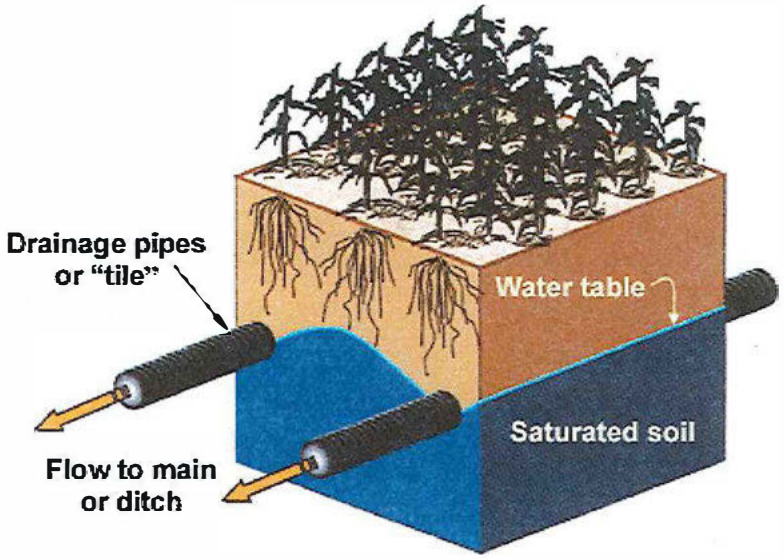
# SOIL TEMPERATURE

## How can soil temperature by managed?

- Mulching: buffers changes in soil temperature
  - hot weather: keeps surface cooler
  - cold weather: keeps surface warmer
    - can also decrease evaporation, which may be undesirable

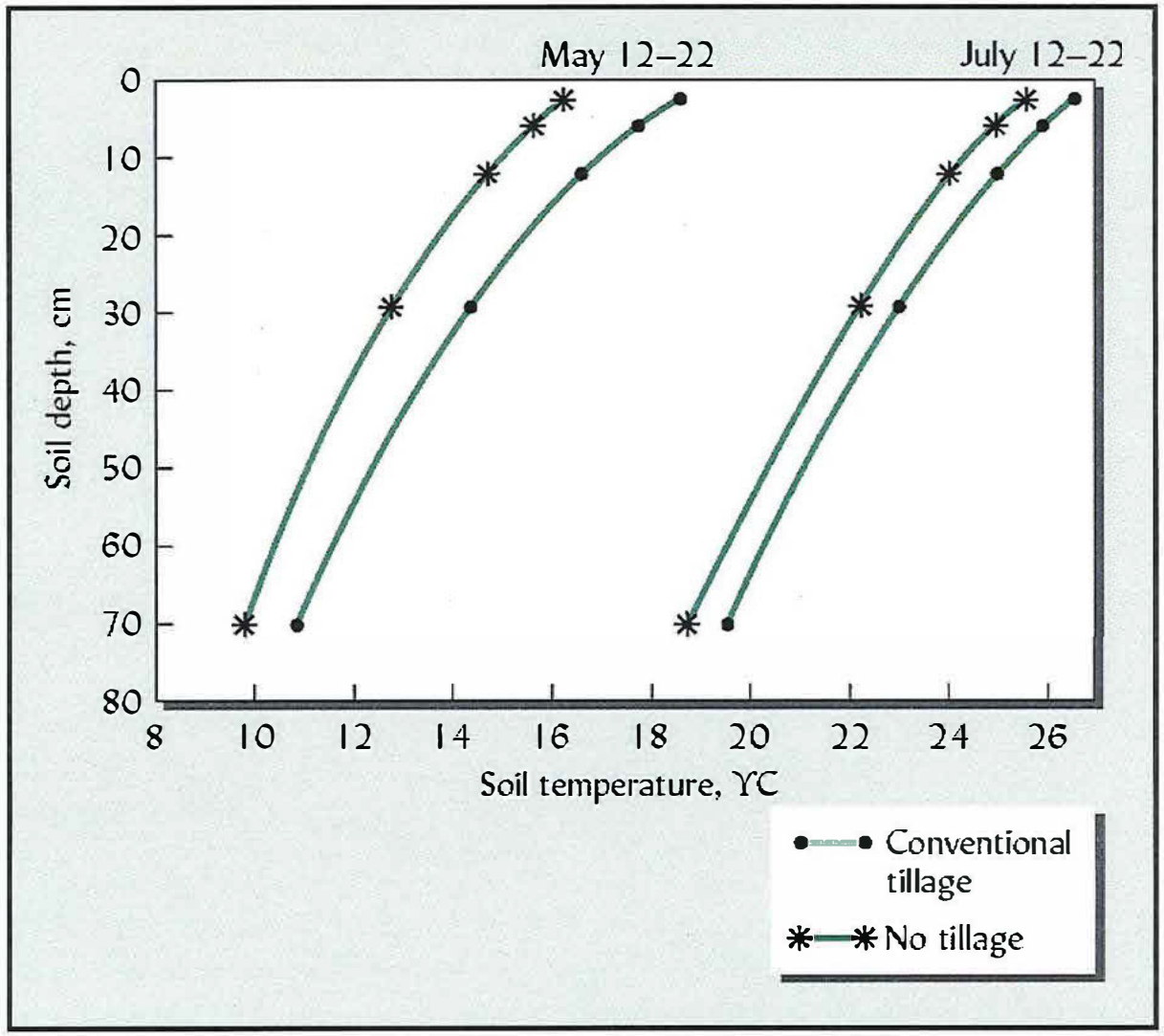
- Drainage: remove water from soil so more energy for warming, less for evaporation

# Mulching




# TILE DRAINAGE TO REMOVE EXCESS WATER

# INFLUENCE OF TILLAGE SYSTEM ON SOIL TEMPERATURE



# SOIL TEMPERATURE

## Final Statement:

- *Soil water management* does more than anything else to influence soil aeration and soil temperatures