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THE RELATIONSHIP BETWEEN TEMPERATURE, HEAT AND ENERGY

DEFINITIONS

temperature - a qualitative measure of the amount of heat energy;
- it is a measure of the intensity or degree of heat energy.

heat - a quantitative measure of the amount of heat energy;
- it is a measure of the quantity or amount of heat energy.

MEASURES OF HEAT (HEAT ENERGY)

calorie (cal) - amount of heat (heat energy) required to raised 1 g of water by 1 ºC.
kilocalorie (kcal) - 1,000 calories
British Thermal Unit (BTU) - amount of heat required to raise 1 lb. of water by 1 ºF
specific heat - amount of heat (# calories) needed to raise 1 g of a substance by 1 oC. (water = 1.0)
heat of fusion - amount of heat (# calories) needed to change 1 g of a substance from solid to liquid at its melting/freezing point. (water = 80 cal/g)
heat of vaporization - amount of heat (# calories) needed to change 1 g of a substance from liquid to gas at its boiling/condensation point. (water = 540 cal/g)

WAYS TO TRANSFER HEAT (HEAT ENERGY)

There are 3 ways in which heat (heat energy) can be moved
1) conduction- flow of heat energy through a medium from molecule to molecule.
2) convection - mass movement of heat energy.
3) radiation- flow of energy as electromagnetic waves, with no transferring medium; when radiation is absorbed it may be converted to heat energy.

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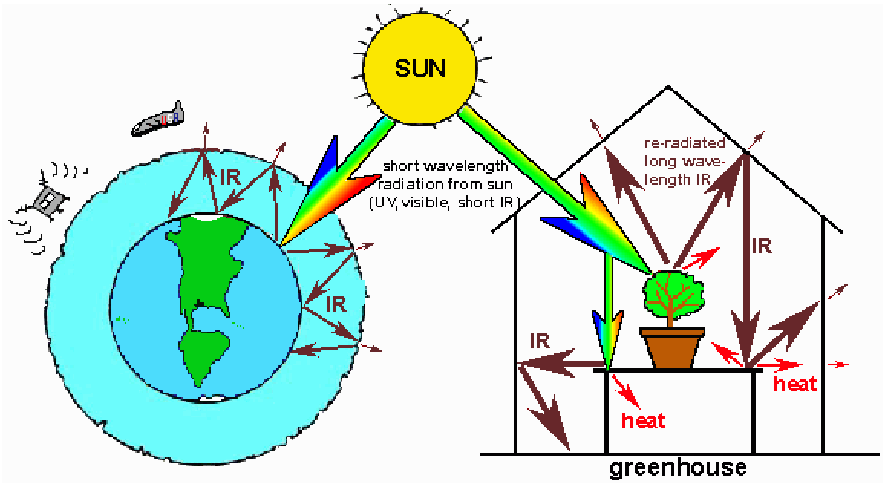
THE GREENHOUSE EFFECT

How the Greenhouse Effect Happens

The **greenhouse effect**gets its name from the heat build-up characteristic in greenhouses during the day. Solar radiation from the sun is composed of relatively short wavelength radiation, with about 10% being ultraviolet (UV), about 40% being visible and about 50% being short wavelength near infrared (IR). This radiation is absorbed by the objects of the earth or inside the greenhouse and the radiant energy is converted into heat energy and the objects increase in temperature. The objects will then begin cooling themselves by conduction, convection and radiation. The radiation emitted (re-radiated) is long wavelength IR. The atmosphere and greenhouse glass are opaque to the long wavelength IR. In the atmosphere, carbon dioxide gas and water vapor absorb the long wavelength IR, which is then radiated back down, thus trapping the long wavelength IR in the earth's atmospheric environment. In the greenhouse, the glass bounces the long wavelength IR back down. This trapped long wavelength IR is absorbed by objects, which causes further heating, and the cycle continues. Thus, the earth and greenhouse act as solar collectors.

Carbon Dioxide Emissions and Global Warming

The increased carbon dioxide emissions from burning fossil fuels (and to a lesser degree massive forest and oil field fires) have caused the level of carbon dioxide in the atmosphere to increase from about 300 ppm to 350 ppm over the last century. This is "fueling" speculation of **global warming** due to an enhanced greenhouse effect. Is it real? Time will tell!



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PRACTICAL APPLICATIONS OF TEMPERATURE RELATIONS

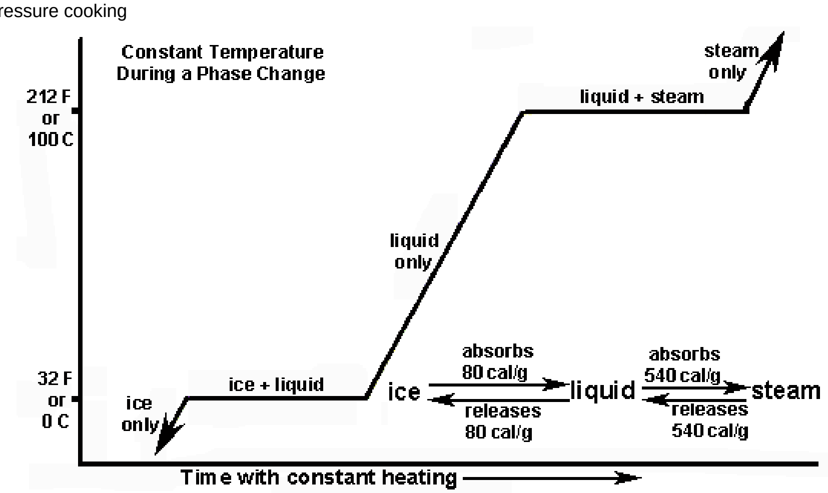
1) specific heat
- stabilizes the temperature of plants (plants are 75-95% water)
- stabilizes the temperature of the environment, esp. around large bodies of water

2) heat of fusion
- used for low intensity heat production
- if you freeze a 55 gal drum of water:
  55 gal x 8 lb/gal x 454 g/lb x 80 cal/g = 16 million calories or 45,000 BTU released

3) heat of vaporization
- causes cooling of plants, animals and the environment
- evaporative cooling system, or fan-and-pad cooling system
- sprinkler irrigate greenhouse or nursery crops in mid afternoon

4) infrared (IR) radiation
- a form of radiation easily converted to heat energy when absorbed and vice versa
- infrared heaters
- radiational cooling
- frost protection with fog, smoke and overhead coverings

5) change of state
- constant temperature when two phases of water are present
- frost protection with overhead irrigation
- pressure cooking



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CLIMATE AND GLOBAL CLIMATIC ZONES

Climate- the average atmospheric conditions over a long period of time.
Weather- the current and temporary atmospheric conditions.

TERMINOLOGY USED TO DESCRIBE CLIMATE OVER SMALL AREAS

1) macroclimate- the climate or weather conditions of a relatively large area, usually 24-50 miles.
2) local climate - the climate or weather conditions of a smaller localized area; ex. a valley, stand of trees, open field, sides of a hill, etc.
3) microclimate - the climate or weather conditions of a very small area, ex. inside vs. outside a canopy, upper vs. lower leaf surface, etc.

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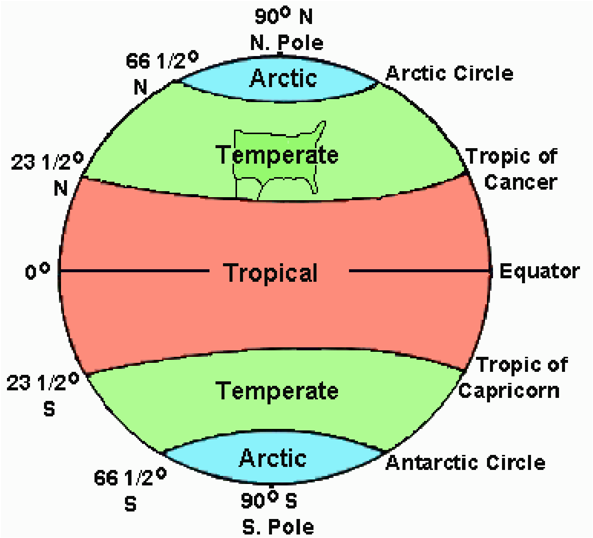
GLOBAL CLIMATIC ZONES - (determined by position of the earth relative to the sun)

1) Tropical Climatic Zone
The area between the 23 1/2º latitude N and S of equator.
Between the Tropic of Cancer (off S. tip of Fla. and middle of Mexico) & Tropic of Capricorn
Warm, rarely if ever freezes

2) Temperate Climatic Zone
The area between the 23 1/2º and 66 1/2º latitude N & S.
Between Tropic of Cancer and Arctic Circle, and Tropic of Capricorn and Antarctic Circle.
Has hot and cold seasons
a)sub-tropical - often used to describe the southern most area of Temperate Climatic Zone (ex. South Florida and Rio Grande Valley), but it is not an official climatic zone.

3) Arctic Climatic Zone
The area between the 66 1/2º N latitude and the N. Pole and the 66 1/2º S latitude & the S. Pole.
North of Arctic Circle, and south of Antarctic circle.
Always cold and frozen



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FACTORS THAT AFFECT TEMPERATURE

1) **Latitude**- average temperature decreases north and south from equator
Due to: **a)** sun's rays spread over greater area
b) sun's rays pass obliquely through thicker layer of atmosphere
2) **Time of Year or Seasonal Variation** - temperature fluctuates most in the Temperate Zone

Seasons: Caused by the unique tilt of earth and orientation to sun
summer solstice - June 21 or 22, when earth's axis is tilted 23 1/2º towards sun.
Warmer due to:
a) sun's rays concentrated over smaller area
b) sun's rays travel through thinner layer of atmosphere
c) days longer
winter solstice - Dec. 21 or 22, when earth's axis is tilted 23 1/2º away from sun
Colder due to:
a) sun's rays spread over larger area
b) sun's rays pass obliquely through thicker layer of atmosphere
c) shorter days
vernal or spring equinox - March 20 or 21, when earth's axis is oriented oblique to, but neither towards nor away from, the sun
autumnal or fall equinox - Sept. 22 or 23, when earth's axis is oriented oblique to, but neither towards nor away from, the sun

3) **Time of Day**
a) **minimum average temperature**: just before sunrise
b)maximum average temperature: mid-afternoon
4) **Elevation or Altitude**
a)small scale - hot air rises, cold air sinks into low areas
b) **large scale** - the temperature decreases 0.6 ºC/100 m or 1 ºF/330 ft increase in altitude
5) **Slopes** - warmest to coldest slopes of a hill sides of a building, etc.: south > west > east > north
6) **Water Bodies** - stabilizes temperature; warmer in winter, cooler in summer
7) **Soils**
a) dark soils warm faster than light soils in spring
b) dry soils warm faster than moist soils in spring

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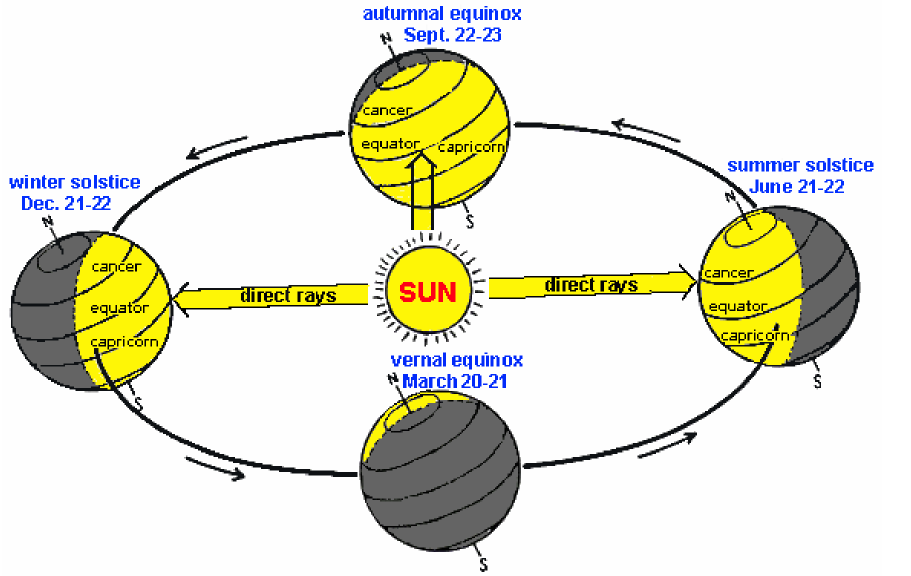
SEASON OF THE YEAR IS DETERMINED BY
THE POSITION OF THE EARTH RELATIVE TO THE SUN
(also determines photoperiod and day length))

The earth's axis is tilted 23 1/2 degrees relative to the axis of the sun. As the earth revolves around the sun, the axis remains pointed in the same direction in space. Notice:

- **At the summer solstice**, the earth's axis is orientated 23 1/2 degrees towards the sun, thus the sun's rays strike the earth at a 90 degree angle at the Tropic of Cancer.
- **At the winter solstice**, the situation is reversed, i.e. the earth's axis is orientated 23 1/2 degrees away from sun, thus the sun's rays strike the earth at a 90 degree angle at the Tropic of Capricorn.
- **At the the autumnal and vernal equinox**, the earth's axis is neither orientated away from nor towards the sun (I made up the term obliquely parallel to describe this, or sometimes I call it cock-eyed parallel), thus the sun's rays strike the earth at a 90 degree angle at the equator.

This unique orientation of the earth to the sun is what generates our seasons. Later in the semester we will show you how this causes the differences in day length or photoperiod between the seasons. This is one of nature's "biological clocks".



[Click for an animated version]

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TEMPERATURE EFFECTS ON GROWTH AND SURVIVAL

Cardinal Temperature - the temperature range in which plants grow and survive.

MINIMUM CARDINAL TEMPERATURE

a) growth: 40-50 ºF (5-6 ºC) for most species
b)survival
  1)tender or chilling sensitive: 32 to 45 ºF (0 to 7 ºC)
  2) semi-hardy plants: 15 to 29 ºF (-9 to -2 ºC)
  3) hardy plants: less than 0 ºF (-18 ºC)

OPTIMUM TEMPERATURE

a) cool-season plants: grow best at 65-75 ºF (18-24 ºC)
  1) in southern U.S.: grow as fall-winter crops.
  2) in northern U.S.: grow in late spring, summer, early fall
b) warm season plants: grow best at 78-90 ºF (24-32 ºC)
  1) in southern U.S.: grow in late spring and summer, early fall
  2) in northern U.S.: grow in summer, but for some warm season crops the growing season may be too short to get good yield.

MAXIMUM CARDINAL TEMPERATURE

a) growth: 90-96 ºF (32-36 ºC), most species
b) survival: 130 ºF (54 ºC), most species.

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HIGH TEMPERATURE EFFECTS ON PLANTS

HOW HIGH TEMPERATURE DAMAGES PLANTS

A) Dies quickly

1) Denatures proteins (unfolding of proteins) - at 130 ^{o}F

B) Dies slowly or just poor growth

1)Desiccation - causes excessive drying-out
2)Sun scald or scorch - desiccation followed by death of tissue
3)Respiration exceeds photosynthesis - depletes stored food

METHODS USED TO DECREASE HIGH TEMPERATURES

A) Soil temperatures

1)mulch - insulates and blocks out light

B) Air temperatures

1)Decrease light intensity (decrease both visible and infrared if possible)
- **a)** lath covering over nursery drops
- **b)** shade cloth or saran over nursery crops or greenhouses
- **c)** shading compound or white wash painted on greenhouse roof
- **d)** colored solution flowing through a double-layered greenhouse roof (primarily decreases IR)

2)Evaporative cooling (relies on heat of vaporization)
- **a)** spray foliage and physical structures during mid-afternoon
- **b)** fine mist or fog injected into a greenhouse
- **c)** fan-and-pad cooling system in a greenhouse

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TYPES OF COLD DAMAGE AND TYPES OF FREEZES

TWO TYPES OF COLD TEMPERATURE INJURY

Chilling Injury - damage or death due to cold, yet above freezing temperatures (32 to 45 ^{o}F).
Freeze Injury - damage or death due to temperatures below freezing (below about 28 ^{o}F).

TWO TYPES OF FREEZES BASED ON HOW THEY OCCUR

1) Radiational Freeze or Frost - temperature drops due to radiational cooling which results in a temperature inversion; occurs on calm, clear nights (see diagram next page).

- **radiational cooling** - loss of heat by long wavelength infrared (IR) radiation.
- **temperature inversion** - a warm air mass above a cold air mass.
- **dew point** - the temperature at which air reaches 100% relative humidity.

2 Types of Radiational Freezes

a) white frost - occurs when the temperature drops below both the current dew point (dew forms) and below freezing (dew freezes).

b) black frost - occurs when the temperature drops below freezing, but remains above the current dew point.

2) Advective Freeze - temperature drops due to the invasion of a cold air mass or convection current.

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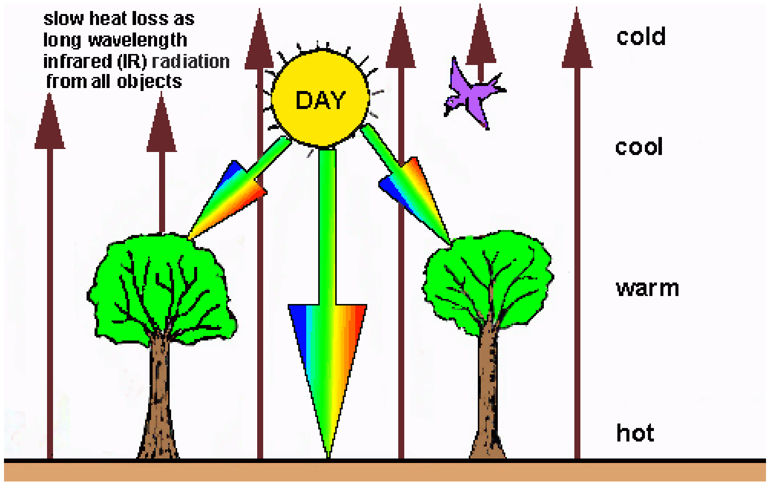
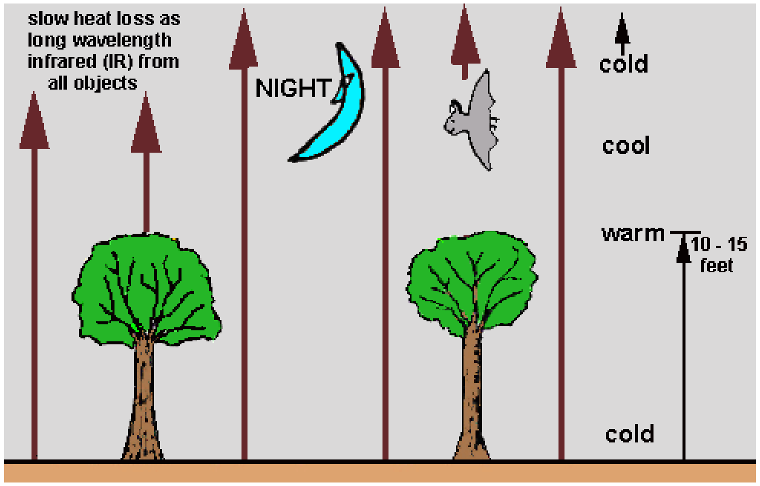
HOW A RADIATIONAL FREEZE DEVELOPS



Heat builds up during the day because the amount of visible and infrared (IR) radiation from sunlight exceeds the amount of long wavelength infrared radiation (IR) re-radiated and lost from the earth's surface. Therefore, the earth's surface warms up, which in turn warms up the air next to the earth, thus the air temperature increases close to the earth's surface.



The earth's surface slowly looses heat by re-radiating long wavelength infrared (IR) radiation, thus the solid objects of the earth's surface cool. This in turn decreases the air temperature next to the earth's surface. If enough energy is lost to drop the temperature below freezing, a frost occurs. Thus, a freezing layer of air occurs next to the earth's surface with a warmer layer of air just above it (about 10-15 feet), which results in the development of a temperature inversion.
The conditions for this to occur are: **a) night, b) no wind, and c) no cloud cover.**

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LOW TEMPERATURE DAMAGE

HOW CHILLING TEMPERATURES INJURE PLANTS (SLOW DEATH)

1) **Increased protein and enzyme breakdown**.
2) **Increased membrane leakiness**
  a) membranes lose selective permeability
  b) often appears deeper green and slightly waterlogged

Sensitive Plants:

- tropical plants
- tropical fruits
- summer annuals and bedding plants
- chilling sensitive vegetables

HOW FREEZING TEMPERATURES INJURE PLANTS (SLOW OR FAST DEATH)

1) **Direct cellular damage** - damage to individual cells.
  a)Very rapid temperature drop
    - ice forms in cytoplasm and ruptures cell
    - seldom occurs, but always fatal
  b)Moderate temperature drop
    - ice forms in cell wall and cytoplasm dehydrates
    - most commonly occurs, not fatal to hardy or cold acclimated plants.

more sensitive vs. more resistant
young tissue vs. old mature tissue
growing tissue vs. dormant tissue
flower buds vs. vegetative buds
roots vs. shoots

2) **Desiccation -** excessive drying-out due to cold soil and dry winds.
3) **Frost heaving -** soil freezes and expands, thus heaving the plant out of the soil.
4) **Bark splitting -** cambium under bark freezes, expands, then splits the bark.
5) **Physical or mechanical breakage (ice damage) -** from weight of ice on plant.
6) **Sun scald or Southwest injury -** excessive desiccation on southwest side of tree; sunlight is brightest on the south and west side.

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METHODS TO PREVENT FREEZE DAMAGE

HOW TO PREVENT A RADIATIONAL FREEZE OR FROST

1) **Decrease rate of radiational cooling**
  a) **hot caps or plastic tents**
  b) **mulches**
  c) **foams**
  d) **fog or water vapor**
  e) **smoke**
2) **Increase air temperature**
  a) eliminate temperature inversion:
    1) **wind machines**
    2) **helicopters**
  b) irrigation
    1) **flood irrigation**; water is warmer and stabilizes temperature (due to high specific heat)
    2) **overhead irrigation**; constant temperature at 32 ºF when liquid/ice present
  c)oil burners or smudge pots

HOW TO PREVENT ADVECTIVE FREEZE DAMAGE

1) **Plant selection** - the **ideal method**, because then no other method is needed
2) **Radiational freeze methods** - some are moderately effective for mild, short freezes.
  a) Insulate: mulch, foam, hot caps (NOT fog or smoke)

b) Increase air temperature: irrigation, oil burners or smudge pots if mild and little wind
c) CANNOT USE: fog, smoke or eliminate temperature inversion

3) **Site selection** - avoid north side of hills, buildings, etc.; avoid low areas, valleys, etc.
4) **Delay development in spring** - avoids damage to new spring growth and flower buds from late spring frost.
5) **Harden-off or cold acclimation in fall**: is a normal part of dormancy and preparation of the plant for for winter.

Naturally triggered by:
a) short days
b) cool temperatures
c) cold temperatures

Allow to occur naturally by observing the following:

1)Do not encourage growth:
- **a)** decrease fertilization
- **b)** decrease watering
- **c)** avoid pruning

2)Avoid stress
- **a)** insect, disease or physical damage
- **b)** poor nutrition and nutrient deficiencies
- **c)** too heavy fruit load

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TYPES OF DORMANCY

Dormancy- a state of inactive growth
Purpose - to survive adverse conditions

TWO TYPES OF DORMANCY

1) **Quiescence** - dormancy imposed by external or environmental conditions

What triggers?
a) Unfavorable environmental conditions
b) External factor, such as hard seed coat
What causes?
Unfavorable environment; too dry, cold, hot, etc.
How to overcome?
Remove unfavorable environment

2) **Rest or Physiological Dormancy** - dormancy imposed by internal or physiological conditions

What triggers?
Environment:
a) short days (SD)
b) decreasing temperatures
What causes?
Internal physiology is unfavorable:
a) low level of growth promoters (e.g. auxin or gibberellic acid), and/or
b) high level of growth inhibitors (e.g. ABA)
How to overcome?
Give period of cold between 32-45 ºF (0-7 ºC), which satisfies the chilling requirement.

- **chilling requirement** - the number of hours of cold between 32-45 ºF (0-7 ºC) required to satisfy rest.

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PLANTS AND ORGANS THAT EXHIBIT REST

Rest is very common amongst **temperate perennial plants**, which are perennial plants that are native to the Temperate Climatic Zone. Rest is a mechanism the plant uses to go dormant starting in the fall in order to survive the cold of winter. Rest also assures flowering, vegetative growth and/or seed germination at the proper time in the spring. The initiation of fall color is a sign of plants going into rest, and the emergence of flowers on fruit trees in the spring is a sign of plants coming out of rest. It is the cold of winter that satisfies rest. If a plant that is in rest is not exposed to the proper amount of cold, it may grow abnormally in the spring and/or may eventually die. That is why we do not grow any of our native temperate trees as indoor plants, instead we use tropical trees that do not need cold to grow normally.

VEGETATIVE AND FLOWER BUD DORMANCY

Cold is required for some trees and shrubs to flower and/or start vegetative growth in the spring, especially temperate trees, shrubs and other perennial plants that are native to the Temperate Climatic Zone.

- **chilling requirement** - the number of hours of cold temperatures between 32-45 ºF

  (0-7 ºC) required to overcome rest (physiological dormancy).
  - **flower buds** - usually have a shorter chilling requirement
  - **vegetative buds** - usually have a longer chilling requirement

FLOWERING BULB DORMANCY

Cold is required for some bulb crops to flower; especially bulbs native to the northern part of the Temperate Climatic Zone, for example tulip.

- **cold storage or bulb chilling** - a period of cold to satisfy chilling requirement of bulbs to

  overcome flower bud rest (physiological dormancy).
  - usually 6-12 weeks at 35-45 ºC (0-7 ºC) in a cooler or refrigerator.

SEED REST OR EMBRYO REST

Cold is required for some seeds to germinate, especially seeds of trees and shrubs which are native to the Temperate Climatic Zone.

- **stratification** - moist, cold (32-45 ºF, 0-7 ºC) storage for 6-12 weeks required to

  overcome embryo rest (physiological dormancy).

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CHILLING REQUIREMENT OF TEMPERATE FRUIT TREES

The chilling hour requirement of fruit trees must be matched to the chilling hour zone where the tree is to be grown. Your local county agent should be able to give you a list of cultivars that are adapted to your chilling hour zone. Reputable nurseries should only sell fruit tree cultivars adapted to your region. Below are the chilling hour requirements of selected cultivars of various fruit trees.

Crop	Cultivar	Chilling Hour Requirement
Peach	Red Haven Red Globe Sentinel June Gold Rio Grande EarliGrande	950 800 750 650 450 250
Cherry	Montmorency	1000
Plum	Ozark Primer Methley	750 600
Apple	Golden Delicious Granny Smith	1000 600
Pear	Maxine Orient	850 650
Pecan	Stuart Desirable	500 400

Grape	American Cultivars French Cultivars	100 none
Citrus	Most Varieties	none

What Happens if you Plant a Fruit Tree in the Wrong Chilling Hour Zone

The table below shows what happens if you plant peach cultivars with different chilling hour requirements in various chilling hour zones across Texas.

Growth Response of Peach Cultivars With Different Chilling Requirements if Planted in Various Chilling Zones Across Texas				
Peach Variety	Chilling Hour Requirement	Brownsville 200 hour zone	College Station 600 hour zone	Wichita Falls 1000 hour zone
Earligrande	250	normal flowering	flowers early in spring, likely killed by late frost	flowers very early in spring, definitely killed by frost
June Gold	650	flowers late if at all; would still grow vegetatively	normal flowering	flowers early in spring, likely killed by late frost
Red Haven	950	flowers very late if at all; would still grow vegetatively	flowers late if at all; would still grow vegetatively	normal flowering

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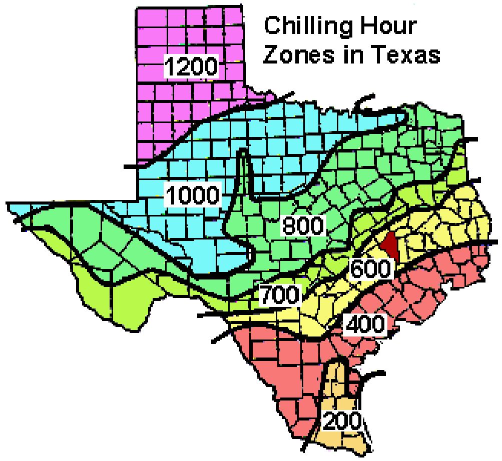
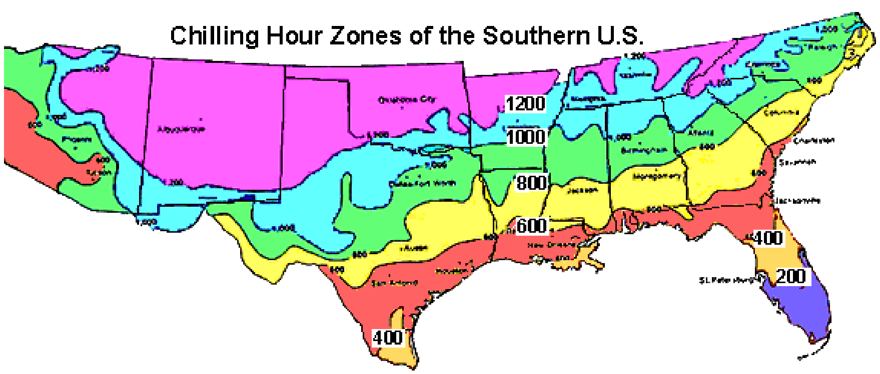
CHILLING HOUR ZONES OF TEXAS AND THE SOUTHERN U.S.

(From: G.R. McEachern. 1990. Growing Fruits, Berries and Nuts: Southwest-Southeast, Gulf Publishing Co., Houston, TX)





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VERNALIZATION AND BIENNIALS

biennial - plants that have a 2 year life cycle:

LIFE CYCLE

1st year - **grow vegetatively** as rosettes or bulbs in late summer-fall
winter - are vernalized by cold of winter to **trigger flower inception**
2nd year - in spring flower forms and develops, called **bolting**

GROWTH HABITS

rosettes - radish, carrot, turnip, mustard, kale, bluebonnet, Indian paint brush
heads - cabbage
bulbs - onion

DEFINITIONS

vernalization - a cold treatment (32-45 ºF for 4-12 weeks) required to trigger or initiate flower formation in biennials.
bolting - flower formation and seed stalk elongation in biennials.
de-vernalization- exposure (1 day to 1 week) to high temperatures (90-95 ºF) immediately after vernalization, which erases the vernalization treatment.
site of perception - growing point (apex) of stems.