Plant Physiology
General

plant physiology is influenced by both:

**genetics**
Some factors that affect life cycle are genetically controlled
→ overall size of plant
→ type of root system
→ general shape of leaf
→ flower color
  etc

sometimes location of cell in young plant body may
determine which genes are turned on or off

eg. in root root genes are on, leaf genes are off

**environmental factors**
(water, temp, light, minerals, parasites, herbivores)

within the limits of genes the expression of a
particular trait may be determined by environmental cues can
affect gene expression

  eg. annual vs perennial
  eg. leaf shape (aquatic vs air leaves)
  eg. changing daylength, variations in rainfall,
temperature
  eg. initiation of sexual reproduction
    → must flower and form seeds before
winter shutdown

plants respond to a variety of environmental
conditions

Some of the most important factors that affect plant
activities include:

1. **Light** (photoperiod)
2. **Temperature**
3. **Nutrient and Water availability**
4. **Plant Hormones**
5. **Disease**

These factors affect many physiological processes in
plants:

1. **Growth** (stems, roots, leaves, buds, etc)
2. **Cyclic Movements**
   - opening and closing of stomata
   - plant movements
     (temporary quicker changes in positions)
   - circadian rhythms
3. **tropisms** (permanent changes in position of plant or parts)
4. **Flowering**
5. **Seed germination**
6. **scenescence, dormancy, leaf & fruit abscission**
7. **transport, transpiration**
1. **Plant Growth**

the main control of plant growth is genetic
- overall size of plant
- type of root system
- size & shape of leaf
- flower color
  
  etc

even with optimal environmental factors not all plants will grow indefinitely.

some parts of the plant grow throughout life
  
  = indeterminate growth

  eg. stems, roots (apical meristem)

other parts stop growing after reaching a certain size
  
  = determinate growth

  eg. leaves, flowers

growth in plants involves:
  
  **cell division**
  **cell elongation**
  **cell differentiation**
    - generalized cells become specialized into tissues

in animals growth occurs throughout the body but at different rates

in plants, growth occurs only in certain areas
  
  = meristems

**meristems**
  
  = embryonic (undifferentiated) cells
  retain ability to divide throughout life
  → they do not mature

two kinds of growth: primary and secondary

A. **Primary Growth**

  increase in length of plant
all plants have primary growth
  herbaceous: all of plant
  woody: young soft shoot & root tips

occurs at apical meristem
  tips of roots and shoots

  **root:**
  cell division
  cell elongation
  maturation, differentiation, eg. root hairs

  **stem buds:**
  have leaf and bud primordia
  differentiation

B. Secondary Growth

increase in diameter (girth)

in areas that no longer elongate

only gymnosperms and woody dicots

extend entire length of stems and roots except at tips

secondary growth produces wood and bark

a few annuals eg. sunflowers, have limited secondary growth w/o forming wood or bark

two areas:

  - **vascular cambium**
    layer of cells forming thin cylinder around stem and root trunk between wood and bark
    between xylem and phloem
    as these cells divide they add more layers to wood (secondary xylem) and inner bark (secondary phloem)

  - **cork cambium**
    thin cylinder of cells in outer bark region
irregularly arranged

cells divide to form cork cells and cork parenchyma

2. **Cyclic Movements**

**Rapid Leaf Movements**

eg. venus fly traps
   → captures insects

eg. sensitive plant,
   → folds leaves and droops in response to touch, electrical or chemical stimuli

result of changes in turgor pressure

very rapid response

can spread throughout plant

specialized cells form **pulvinus** or hingelike area at base of two leaves or leaflets
   → contains cells “overfull” with water

when stimulated by touch, electricity or chemicals
   → increases membrane permeability to K+
   → K+ rushes out of cells
   → water leaves by osmosis
   → decreases turgor
   → leaf wilts and folds

recovery takes considerably longer than original response

**Solar Tracking**

is a slower but probably similar response

for leaves it allows maximal exposure to light for photosynthesis
eg. solar tracking by sunflowers, soybeans, cotton leaves and/or flowers
   \rightarrow somewhat slower but same principle
   \rightarrow many have pulvinus at base of petioles

**Biological Clocks**

plants, animals, and microorganisms have biological clocks that approximate a 24 hr cycle = circadian rhythm

[vs photoperiodism – which keys on time of year]

w/o any external cues,
   \rightarrow circadian rhythms repeat every 20-30 hours

eg. stomatal cycle
   \rightarrow operates independently of light and darkness

eg. "sleep" movements

   day – leaves are horizontal
   night – they fold up or down

   don’t know the significance of this

eg. night flowering plants ?

in nature rising and setting sun sometimes resets this biological clock

for many plants, phytochrome has been implicated in resetting this clock
3. **Plant Tropisms**

A permanent change in position of plant part

directional growth

may be positive or negative (toward or away from) a stimulus

**Phototropism**
→ response to light

eg. most shoots have + phototropism

eg. some vines have – phototropism as they begin to grow (grow toward shade = toward “host” tree), then + phototropism (as they climb tree)

**Gravitropism (=geotropism)**
→ response to gravity

eg. stems – geotropism
eg. roots - + geotropism

roots have been best studied
root cap is center of gravity perception
contains special cells that have large starch grains = **statoliths**.
statoliths collect toward bottom of cells in response to gravity
but roots grown w/0 statoliths can also show +geotropism

**Thigmotropism**
→ response to mechanical stimuli
eg. twining of tentrils

other tropisms can be cause by water, temperature, chemicals and oxygen
4. **Flowering**

Environment (light, temperature, etc) plays an important role in flowering.

**Light**

Flowering is affected by light, especially in temperate environments.

**Photoperiodism**

= any response of plant to lengths of daylight and darkness.

The effects of photoperiod on flowering have a direct effect on the geographical distribution of plants.

Wrt flowering, plants are classified as:

1. **Short day plants** (=long night plants)
   flowers when night length is ≥ some critical value.
   It is NOT due to short period of daylight.
   Plants bloom in late summer or early fall.
   
   Eg. chrysanthemums, asters, ragweeds, pointsettas

   Short day plants don’t do well at high latitudes (>~50°)
   → since summer days (ie. the growing season) are too long.

2. **Long Day** (=short night) plants
   Flower when night length is ≤ some critical value.
   
   These are found more often at very northern latitudes.

   In temperate areas, these plants bloom in late spring, summer.
   
   Eg. clover, spinach, black eyed susan, lettuce.
3. Intermediate – Day Plants
flower when exposed to days and nights of intermediate length
will not flower when daylength is too long or too short
eg. sugarcane, some grasses

4. Day – Neutral Plants
many of these plants originated in tropics where daylength does not vary much during the year
flowering is triggered by some other factor
may flower throughout the year in temperate areas
eg. tomatoes, dandelions, stringbeans, pansy

Photoreceptors
these responses to light require some kind of photoreceptor structure or molecule
something that is light sensitive

phytochrome = a light sensitive, blue green pigment
found in cells of all vascular plants
acts as light trigger for flowering

Phytochrome is also involved in other plant responses to light:
→ seed germination
→ “sleep” movements in leaves
→ shoot dormancy
→ leaf abscission
→ pigment formation in flowers, fruits and leaves
→ stem growth in response to shading to reach more light

Temperature
certain plants have specific temperature requirements in order to flower
eg. winter wheat – 1 yr life cycle

eg. carrots – 2 yr life cycle – if no low temperature, they may not flower in 2nd year

**vernalization**

= require exposure to low temperatures in order to flower

the part of the plant that must be exposed varies:

eg. moist seeds vs germinated seedlings

can treat plant with gibberellins to eliminate this low temperature requirement
5. Seed Germination & Early Growth

numerous factors affect whether or not a seed germinates:
   a. presence of adequate water
      eg. not drought, plenty of rainfall
   b. adequate oxygen
      eg. saturated soil, buried too deeply, etc
   c. proper temperature
   d. proper amount of light
      eg. some, not too much; not buried too deeply
   e. physical abrasion
   f. genetic factors

a. Water Absorption
   process begins with absorption of water by seed
   = imbibition
   involves osmosis
   often swells to several times its original size

   eg. many desert plants often contain high levels of abscissic acid
   which prevents germination
   → it is washed out only when rainfall is sufficient

b. Large Energy Requirement
   germination requires a great deal of energy
   converts stored food in cotyledons or endosperm
   to ATP by aerobic respiration
   → therefore needs oxygen for germination

   some plants, eg rice, can begin growth without
   oxygen → flooded soil

c. Temperature
   Temperature Affects Germination
   each species has an optimal temperature at which the largest
   number of seeds germinate
   → most ~ 25-30º C (77-86º F)
   eg. some seeds, eg apple, require long exposure
to cold before seeds will germinate

d. Light
   some plants, especially those with tiny seeds require light for
   germination
eg. lettuce seeds
they will germinate only if very close to surface of soil
otherwise it may not have enough food reserves to
grow to surface to begin photosynthesis

e. Physical Abrasion
eg. legumes (beans, peas) have extremely hard thick seed coats
that prevent water and oxygen from entering
\Rightarrow \text{scarification induces germination}
\Rightarrow \text{can be physical (digestive tract) or chemical (acids)}

f. Genetic Factors
in some seeds, internal factors may prevent
germination even when all external condition are favorable
many seeds remain dormant because:
\Rightarrow \text{embryo is immature and must develop further}

the first part of the plant to emerge is the radicle
(embryonic root)
\Rightarrow \text{its tip is protected by root cap and so grows}
\text{straight down into the soil}

next the plant shoot emerges,
\Rightarrow \text{it has no protective cover}
in dicots the shoot forms a hook and pulls the
tips of the cotyledons up through the soil
in monocots (corn, grasses) have a special
sheath of protective cells (=coleoptile) that surrounds and
protects the young shoot

the leaves and stem then grow up
through the middle of coleoptile
Coordination and Control – Hormones

Activities of complex organisms can be coordinated by nerve impulses or by chemicals called hormones.

**Hormone** = chemical produced in one tissue or organ has its effect in another tissue or organ.

virtually all multicellular life produces hormones to help coordinate and control growth reproduction and development.

only animals have a nervous system as an additional method of coordination and control.

**Hormone Characteristics:**

1. relatively small chemicals, usually organic chemicals that affect cells and tissues

2. effective in very small quantities

3. may elicit different responses in different organs or tissues
   
   may trigger one response in one part of a plant and inhibit that response in another part of same plant

4. often interact with other hormones to create **synergistic** or **antagonistic** effects

   most plant processes are the result of interactions between several different plant hormones

   often difficult to determine which hormone is the primary cause of a particular response

   a plant’s actual response may be the result of changing “**ratios**” of hormones rather than the specific effect of each hormone

   also, other environmental factors may tend to promote the same process

**Major Plant Hormones:**

Auxins

Gibberellins
Cytokinin
Ethylene
Abscissic Acid
Florigen
**Auxins**

1st plant hormone discovered by Charles Darwin and son, 1880

they noticed that plant on windowsill bends toward light

they shielded tip of canary grass seedlings from light → no bending occurred
when tip was removed → no bending
when bottom of shoot was shielded → shoot still bent toward light

conclusion: some influence is transmitted from the upper to the lower part of the plant causing it to bend

Auxins = “to increase”
mainly indoleacetic acid

are a group of hormones that regulate growth in many parts of a plant

produced in the apical meristem and in young leaves and seeds

the concentration of auxins can affect their activity in the same tissues, eg.
in low amounts → promotes cell growth
in large amounts → inhibits growth

today we have identified several important functions of these Auxins:

1. **promotes cell elongation in stems**
   → stems (shoots) bend toward light (=phototropism)

2. **inhibits cell elongation in roots**
   → roots bends downward (away from light) (=geotropism)
   has inhibitory effect on “down” side of root

3. **promotes apical dominance**
   some plants tend to branch out very little as they grow, others become quite bushy
   growth in ‘non-bushy’ plants occurs mostly from apical meristem rather than axillary buds = apical dominance
auxins produced in apical meristem inhibit development of axillary buds
snip off apical bud to get branching
eg. pruning, pinching

4. stimulates fruit development
the growth and development of the ovary of a flower into a fruit are controlled by auxins produced after the flower has been pollinated:
when unpollinated flowers are treated with auxins:
    ovary enlarges and becomes a seedless fruit
    eg. tomatoes, watermelons, peppers, strawberries

[other hormones are also involved in fruit development]

5. leaf abscission (& fruit drop)
all trees (and other perennial plants) shed leaves
    evergreen → shed leaves yearround, uncoordinated
deciduous → drop all leaves at same time
    eg. in temperate areas – before winter
        helps them survive low temperatures of winter
        metabolism and photosynthesis slow
        saves water
    eg. in tropical areas – before dry periods
other plant parts also separate from plant as normal part of life cycle:
    eg. flowers and fruits fall

same process for fruit drop
    → artificially applied auxins to fruit delay fruit drop and produce larger fruits

synthetic auxins are used as herbicide/defoliant for broadleaved plants (doesn’t kill grasses – don’t know why)

many of the worlds most important crops are grasses:
    eg. wheat, corn, rice

these herbicides are used to kill weeds that compete with these crops in the fields

these herbicides disrupt plant’s normal growth
    → exaggerate growth in some parts
    → inhibit growth in others
    → disrupt auxin ratio and cause defoliation
eg.  2,4-D; Agent Orange
during Vietnam war they were used to defoliate large
areas to expose hiding places of enemy and to destroy
their crops
used from 1961-1971
after effects:
  a. the dioxin in the mix was later found to cause:
     >health problems
     >incidence of some forms of cancer
     >birth defects and stillbirths
  b. 20-50% of mangrove forests in S Vietnam
     were destroyed
  c. 30% of nations commercial hardwood forests
     were killed
  d. enough crops were destroyed to feed 600,000
     people

6. **promotes adventitious root development**
   auxins also control the development of **adventitious roots**
   \[ \text{treating stem with auxins promotes root development} \]
   eg. root stimulators are synthetic auxins used to
      stimulate root development on cuttings for asexual
      propagation

**Gibberellins**

in 1920’s a Japanese biologist was studying a disease
of rice seedlings that caused rice plants to grow extremely tall and
spindly, then fall over and die
= “foolish seedling disease”

he found that its cause was a chemical produced by a
fungus called gibberellin

took until the 60’s to discover that gibberellins were
also plant hormones with a variety of effects in plants

gibberellins are produced mainly in apical leaf
primordia (not meristem)

also found in seeds, young shoots, and roots

1. **promotes stem elongation**
   causes excessive lengthening of stem
   (not just one side like auxins)
dwarf plants lack gibberellins
\[ \rightarrow \text{when gibberellin is added they grow to normal heights} \]

also involved in **bolting** in biennials
\[ \rightarrow \text{sudden elongation of stem usually with flower head} \]
\[ \text{eg. lettuce, cabbages} \]

eg. most grape growers spray vines with gibberellins to increase length of branches between fruit clusters (more air, fewer fungal infections)
\[ \rightarrow \text{produces larger, healthier grapes} \]

2. **can stimulate flowering**
   in *some* (long-day) plants
   can substitute for low temp in biennial plants to get them to flower in 1 year = **flower forcing**

3. **can stimulate seed germination**
   many seed plants require specific day/night cycle or low temperatures to germinate

   gibberellins can substitute for temp or light cues in these plants to get them to germinate (eg. lettuce, oats, tobacco)

   gibberellins may also be involved in plant movements and flowering

**Cytokinins**

during 40’s & 50’s researchers doing tissue cultures found that a chemical in coconut milk induced cell division in plant cells

1. **promote cell division**
   cytokines promote cell division and differentiation
   they must be present in cells for them to divide
   \[ \rightarrow \text{plant cells grown in culture without it will enlarge enormously but will not divide until cytokines are added} \]

2. **promotes cell differentiation**
   interacts with auxins and other hormones to affect differentiation of shoots, buds
   eg. \( > \text{cytokine/auxin ratio} \rightarrow \text{induces shoot development} \)
   eg. \( < \text{cytokine/auxin ration} \rightarrow \text{induces root development} \)

3. **delays senescence & aging**
Plants receive a continuous supply of cytokines from roots
   - when cut they age and die rapidly
   - if sprayed on cut leaves and stems they will remain green longer while unsprayed leaves will turn yellow and die

4. **can be used to break dormancy**

**Ethylene**

a gas

1st discovered in plants in 1934

1. **promotes fruit ripening**
   as fruit ripens it produces ethylene which accelerates the process

   eg. black spots on bananas are spots of ethylene production
      ethylene is used commercially to promote uniform ripening in bananas that are picked while green (longer shelf life)
      eg. “one rotten apple spoils the lot”
      eg. promotes uniform ripening in green bananas

2. **promotes seed germination**

3. **involved in plant responses to pathogens and wounds**

also interacts with auxins and cytokines to affect abscission & stem elongation

**Abscisic Acid**

discovered in 1963

[ does NOT induce abscission]

1. **promotes dormancy in woody stems**
   as winter approaches, woody plants cease growth and develop protective bud scales under influence of abscisic acid

2. **promotes seed dormancy**
   seeds have a high concentration of AA and cannot germinate until these levels are reduced
   seeds cannot germinate until high level of AA is removed by spring rains
a mutant corn unable to make AA germinates on ear

interacts with gibberellins and cytokinins in dormancy

→ in seeds as level of aa decreases through winter, level of gibberellins increases

→ cytokines also have been shown to be able to break dormancy

3. acts as plant stress hormone
   eg. protects cells from drought, freezing, salination

Florigen [hypothetical hormone]

experiments done with tobacco plants indicate that both flower-promoting and flower-inhibiting chemical exist

   eg. long day grafted to day neutral and exposed to short nights
      → both flower, neutral plant flowers sooner than it normally would
**Transport**

Transport in plants is not like fluid transport in animals

In most animals fluids are circulated in the body, usually using a muscular pump to push fluids along

Plants have no “muscle” cells and generally do not show movement – they have no pumps to pump fluids

They mainly use **passive physical processes** such as diffusion, osmosis, and cohesion/adhesion to move things around in the plant body

There are two major transport systems found in most plants:

- **xylem**
- **phloem**

**xylem:**
Water and minerals are transported in the xylem and travel only upwards

**phloem:**
Dissolved sugars travel in the phloem from the leaves to other parts of the plant
Xylem Transport

water and minerals are transported from the roots to the leaves

main cells in xylem are

vessel elements
tracheids

→ both are hollow, dead cells, connected end to end to form long tubes

water & minerals are absorbed by root hairs and mycorrhizae

once it enters xylem it travels quickly to leaves by process of transpiration (or evapotranspiration)

the driving force of water movement is the “pull” of transpiration

→ wick-like force

the key to transpiration is the stomata of the leaves

as water is evaporated from the stomata

→ tension is produced resembling the “sucking” on a straw

→ cohesion of water molecules “pulls” more water up the plant to replace it

→ Tension-Cohesion Theory of xylem transport

[=sucking-sticking theory]

water must form an unbroken column of water molecules for process to work

a single bubble destroys the flow and stops transpiration eg. cut christmas trees

in transpiration dissolved minerals are carried passively by the water

the plant does not expend any energy
the only limit to how “high” a plant could draw water by transpiration depends on
→ the cohesion of water molecules,
→ the diameter of the “straws” (xylem cells),
→ the pull of gravity, and
→ the weight of water

eg. biologists have calculated that transpiration should be able to pull water up “pipes” as long as 450’ (=150 m)

the tallest trees on earth are 375’

how tall could a tree get on the moon? mars?

99% of all water taken up by plants ends up in the atmosphere
→ the water is used to get a small amount of water and minerals to leaves for photosynthesis

eg. 1 corn plant → 52 gallons/season

must be a balance of water lost through evaporation and water available in soil

Transpiration occurs whenever stomata are open

in most plants stomata are open in daytime when photosynthesis is occurring and closed at night to conserve water

if water is not available to open stomata the leaf wilts

stomata remain closed until water is available

any factor that increases transpiration too much will cause stomata to close:

1. high temperatures
   10º C increase doubles rate of evaporation
2. high wind
   hot windy days cause water stress in plants
3. low humidity
   many houseplants are native to tropics
eg. Houseplants are usually tropical in origin:
    have large leaves, open exposed stomata
    no adaptations for conserving water
    these plants may spend most of their time with
    closed stomata and little growth
    watering heavily doesn’t solve problem unless
    done correctly need to water entire root zone
    otherwise new growth areas will die
    more houseplants are killed by overwatering than
    underwatering

plants have evolved many adaptations to conserve
water

1. desert plants, eg cacti, have changed their
   physiology so that **stomata are open at night** and closed during
   the day

2. **succulents** store scarce water in leaves or
   stems

3. desert & cold climate plants often have much
   **thicker cuticles**

4. some plants **lack stomata on top of leaves**, 
   only have them on protected side

5. **sunken stomata**

6. **narrow needlelike leaves** or rolled leaves
   reduce surface area for evaporation
   eg. conifers

there are a few instances when the flow of water is
reversed and moves into soil
eg. high salt content of soil
→ fertilizer burn
→ salinization
**Phloem Transport**

photosynthesis converts water and carbon dioxide to a sugar, called glucose, and oxygen

the sugar is used by all plant cells for energy production

all living cells break down sugar for energy

unlike heterotrophs, autotrophs can **make** their own sugar instead of having to **eat** it

oxygen is released through stomata of leaves

in most plants, glucose is converted to **sucrose** (table sugar)

sucrose enters phloem to move to other parts of plant

In phloem, materials can move both ways = **translocation**

phloem is composed of living cells

movement of sugar into phloem cells is an active process and requires energy

inside the phloem, sugar goes down a concentration gradient
  moves from areas high in sugar (leaves)
  to areas low in sugar (eg. roots, stem)

movement is in both directions depending on sugar concentration
  eg summer storage
  eg. new growing buds

woody plants have "**rays**"
  = branches of vascular tissue that move materials horizontally in stem

translocation in phloem is much slower than transpiration in xylem
  [6-22′/hr in phloem vs 500′/hr in xylem]
Plant Chemicals

many plants contain toxic alkaloids
toxic to herbivores

may be pharmaceutically important

some used as hallucinogens

secondary products – help protect plants against
excessive herbivore damage
eg. milkweeds – cardiac glycosides
eg. waxes
eg. lignin – hardens cell wall of woody tissue

sporphollenin
toughest of all substances
in walls of spores and coats of pollen
polymer resistant to almost all kinds of
environmental damage
did not originate in plants, also found in
zygotes of some red algae