

Plant Physiology

General

Photosynthesis

probably the most characteristic "thing" that plants "do" is photosynthesis

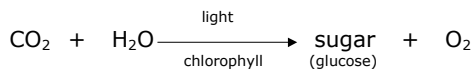
almost all plants are **autotrophs**

→ use **energy** from the sun to make **sugar** and other organic molecules out of simple nutrients

photosynthesis requires **carbon dioxide & water**

CO₂ enters through **stomata** or pores

water is absorbed through **roots**



[photosynthesis converts water and carbon dioxide to sugar and oxygen]

→ these sugars can then be broken down as needed for **energy**

photosynthesis uses several chemical **pigment** to absorb the energy from sunlight

the main light sensitive pigment able to absorb solar energy in both plants and algae is **chlorophyll**

this chlorophyll is contained with the **chloroplasts**

plants also have other "**accessory pigments**":

carotenoids – mainly yellow, orange

but usually their colors are masked by an abundance of chlorophyll

fall colors are seen as a deciduous plant shuts down and chlorophyll is broken down and recycled leaving the colors of the other pigments

reds come from anthocyanins made to protect leaves as they recycle nutrients from the breakdown of chlorophyll

[Application]

researchers are studying the structure of the chloroplasts to improve efficiency in the design of solar collectors

today (2006) the most efficient solar cells capture only ~17% of solar energy that lands on them, while plant cell capture 30-40%

Plant Nutrition

heterotrophs must eat a variety of organic compounds to build cells and to break down for energy

since plants produce their own organics they require relatively few simple **inorganic** nutrients

like most living organisms plants need some form of Carbon, Hydrogen, Oxygen & Nitrogen

carbon, hydrogen and **oxygen** come from the air in the form of CO₂, H₂O & O₂

nitrogen & most other nutrients such as Phosphorus and Potassium comes from the soil:

van Helmont (1600's) took tub with 200 lbs of soil and planted a 5 lb willow tree in it

after 5 years:

the willow weighed 164 lbs
the soil weighed 2 oz

much of global climate change is being caused by increasing amounts of CO₂ in the atmosphere

many oil and coal companies have touted the beneficial effects of CO₂ on plant growth

eg. bristlecone pines and other native species have shown enhanced growth over the past 50 years

what they ignore is that many other native species do not benefit from increasing CO₂

in most cases; **Nitrogen & Phosphorus** are most likely to limit plant growth (hardest to get nutrients),

all fertilizers contain: N, P and K, in various concentrations

[Application]

agriculture & gardening

plants, mostly nonnative species, are selected for fast, lush growth need many more nutrients (and water) than native plants must supplement with fertilizers

eg. Nitrogen

in most plants, Nitrogen is absorbed as inorganic minerals from the soil

however some plants are able to get their nitrogen in other ways:

some plants can grow in N-poor soil using a symbiosis with **N-fixing bacteria** that can extract N from the atmosphere and convert it to a more useable form

some plants are **carnivorous** and get their nitrogen from digesting insects and other animals

→ tend to grow nitrogen poor soil

over 500 species have been described

→ N America has the most diverse carnivorous plant fauna

most prefer damp boggy soils

attract insects through color, smell, nectar

a few plants not considered to be "carnivorous" may still be able to get at least some nutrition from them:

eg. petunias - covered with sticky hairs

eg. potato, tobacco, rhododendron and teasel produce poisons that kill insects and may absorb some nutrition from them

eg. a rare Brazilian plant produces underground leaves that trap, kill and absorb roundworms

Heterotrophic Plants

a few plants get at least some of their organic molecules in other ways than photosynthesis

they are therefore (at least partially) **heterotrophic**

a few of these have completely given up photosynthesis

eg. parasitic plants

3000 species of parasitic plants

largest group are the mistletoes (~800 sp)

mostly tropical and subtropics

but also includes:

indian paintbrush (a hemiparasite)
sandalwoods
dodders (eg. *Cuscuta* sp.) of the morning glory family
broomrapes and figworts
rafflesia

roots grow into host plant

extract water, minerals and nutrients from vascular system of host

some have given up photosynthesis altogether and get *all* their organics from their host

eg. dodder, coral root orchid, broom rape,

eg. pants parasitic on fungi

some plant roots parasitize the abundant **fungi** that grow in and on the forest floor

some of these have also completely lost the ability to do photosynthesis

eg. snow plant
also produces its own heat that can actually melt snow

Root Grafts

one other way that perennial plants might get access to both organic and inorganic foods are through root grafts

as roots grow they encounter roots of other plants can be same or different species

may grow together to form graft

root grafts are known for over 160 species of trees

eg. birch, maple, oaks, aspen

nutrients can pass between them

may be of advantage for a plant growing in poor soil that is connected to a plant nearby growing in good soil or near a creek or pond

hormones can also be exchanged

sometimes events like flowering or autumn colors in deciduous plants are coordinated

eg. aspens tend to grow in large interconnected colonies and typically all members of the colony begin to show fall colors at the same time

but some diseases can also spread directly from tree to tree through these root grafts

eg. oak wilt often spread this way

a common method to control oak wilt is to trench around an infected tree

→ breaks any root grafts with other trees

Halophytes

so far we've talked about how plants get nutrients and minerals when they are in short supply

under some situations plants have to deal with the opposite problem

→ **too many** minerals and salts in the soil

if soil contains too many minerals; ie. is too salty the plant may be unable to absorb water effectively

→ salty soil can actually suck the water out of the plant by **osmosis** ("water follows salts")

most plants are fairly sensitive to high concentrations of salts in soil

eg. too much fertilizer can kill a plant

eg. farmland that is continually irrigated becomes less fertile as salts and minerals build up from evaporation

=**soil salinization**

millions of acres of farmland have been removed from cultivation because of salinization

especially in dry climates

but a few plants can grow in high salt concentrations

equivalent to the saltiness of sea water ~3% salt

these plants are called **halophytes**

eg. many plants of the sea shore and salt marshes

halophytes have special cellular adaptations that

prevent them from taking up salt

or

allow them to secrete excess salt

eg. trichomes (leaf hairs)

Oxygen for Respiration

in addition to needing **oxygen atoms** to build organic molecules plants also need **oxygen molecules** (O₂) to break down organic molecules for energy

→ **aerobic respiration**

since plants are much less active than animals they have a very low O₂ requirement;

1-2% is sufficient to maintain aerobic respiration

→some O₂ diffuses across cuticle and closed **stomata** of leaves and herbaceous stems

→in roots, well drained soil usually has enough air spaces to provide oxygen for roots

→when soil is saturated with water cells can use anaerobic respiration temporarily

but cant grow and do normal metabolism until the soil drains

if soil remains flooded too long they will die

→cypress & mangrove trees have adapted to living in continuously saturated soil by producing **pneumatophores** ("cypress knees") which act like snorkels to bring O₂ to the roots

Transport in Plants

most plants are large enough that they need some way to be able to move materials around

only the smallest plants lack a transport system

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 them along

Plants have no "muscle" cells – they have no pumps to push fluids around

plants mainly use **passive physical processes** such as diffusion and osmosis to move things around

There are two major transport systems found in most plants:

xylem
phloem

A. Xylem Transport

xylem is generally made of larger thicker-walled cells that die at maturity to form long hollow 'straws' that extend and branch throughout the plant; from roots to leaves

water & minerals are absorbed by root hairs and mycorrhizae and are transported from the roots to the stomata in the leaves

→ in one direction only

the driving force of water movement in the xylem is the "pull" of transpiration

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

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

a single bubble destroys the flow and stops transpiration

eg. cut flowers, cut christmas trees

dissolved minerals are carried **passively** by the water

the plant does not expend any energy

transpiration also helps to **cool** the plant

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?

transpiration requires lots of water

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 metabolism

eg. 1 corn plant → 52 gallons/season

eg. on a warm day a maple tree may lose 50-60 gallons/hour

eg. an acre of temperate forest transpires ~8000 gallons/day

stomata can be open or closed by the action of two **guard** cells that surround each pore

transpiration only occurs when the stomata are open:

stomata are usually open in the daytime and closed at night

wilting = too much transpiration

stomata will close
remain closed until water is available

local environmental variations can affect water loss & trigger opening and closing of stomata

1. high temperatures

10° C increase doubles rate of evaporation

2. high wind

hot windy days increase transpiration and cause water stress in plants

3. low humidity

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

4. low CO₂

→ stomata open even after dark

5. water stress

→ stomata closed even in daytime

6. circadian rhythm

→ internal clock; stomata open and close at same time each day

in many habitats or certain seasons, water can become limited

→some 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**

1-3% of water can be lost through epidermis

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

5. **sunken stomata** or **thick leaf hairs**

not as exposed to air currents

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

eg. conifers

B. Phloem Transport

phloem is composed of living cells joined end to end

phloem generally moves organic molecules such as sugars, hormones, secondary plant compounds, etc throughout the plant

in phloem, materials can move in any direction = **translocation**

in some plants glucose and fructose are combined to make sucrose which is then transported in phloem

eg. sugar cane, sugar beets, maple sap

movement of sugar in phloem

is partly by **passive diffusion** of materials down a concentration gradient

moves from areas high in sugar (leaves) to areas low in sugar (eg. roots, stem)

eg. new growing buds

and partly an **active process** that requires energy

sugars are actively moved from cell to cell or concentrated in certain plant parts

translocation in phloem is much slower than transpiration in xylem

[6-22'/hr in phloem vs 500'/hr in xylem]

Plant Behaviors

most regard plants as completely unresponsive organisms

however, more and more we find plants capable of some pretty complex activities that, in animals, we would call "**behaviors**"

some common plant behaviors:

- a. plant movements
- b. temperature control in plants
- c. parasitic plants "pursuing" hosts
- d. plants fighting each other for resources
- e. plant defensive behaviors

A. Plant Movements

while plants are generally unable to move about as individuals; like all living organisms they are capable of at least some simple forms of movements:

three general kinds of movement in plants:

- a. simple movements (=tropisms)**
- b. rapid leaf movements**

c. cyclic plant movements

A. Simple Movements (Plant Tropisms)

= any permanent change in position of a plant or a part of a plant

we've already discussed some tropisms:

phototropism and **geotropism**

also **Thigmotropism**

→ response to mechanical stimuli
eg. twining of tendrils

other tropisms can be caused by **water, temperature, chemicals** and **oxygen**

B. Rapid Leaf Movements

eg. sensitive plant

→ folds leaves and droops in response to touch, electrical or chemical stimuli

eg. venus flytrap

→ captures insects

very rapid response

can spread throughout plant

produced by specialized cells that form a hingelike area (=pulvinus) at the base of two leaves or leaflets

when stimulated by touch, electricity or chemicals causes ions and water to quickly leave cells

→ leaf wilts and folds

recovery takes considerably longer than original response

C. Cyclic Plant Movements

slower than rapid movements and occur repeatedly over some kind of cycle

eg Solar Tracking

for leaves or flowers it allows maximal exposure to light for photosynthesis

eg. sunflowers, soybeans, cotton

is a slower but probably similar mechanism to rapid movements

eg. "sleep" movements

day – leaves are horizontal

night – they fold up or down

B. Temperature Control ("warm blooded" plants?)

the temperature of most plants reflects the temperature of their surroundings

but some plants are able to generate relatively large amounts of heat

they can turn this ability on and off

eg. some generate heat in late winter/early spring

plants produce heat much more efficiently than do animals (ie. *all* the energy extracted from food by the mitochondria is converted to heat; in animals only about 40% is converted to heat, the rest into ATP)

some plants generate this heat by burning fat just like animals

this heat is used in several ways:

→ so plant can get a jump on the growing season

eg. skunk cabbage (*Symplocarpus foetidus*; arum family) can maintain tissue temperature of 16-24° C in all weather
can even melt snow
generates heat by burning starch in special cells

eg. Blue moonwort of Swiss Alps (primrose fam) autumn develops thick leathery leaves that lie flat on ground
covered by snow to depth of several feet
in spring melting snow trickles to plant
generates heat that further melts snow

eg. philodendron can maintain a temperature of 46° C even in 4° weather

→ to enhance pollination

eg. plants in arum family generate heat to attract flies for pollination

eg. voodoo lily (*Sauromatum guttatum*) parts of flower heat up to vaporize and disperse attractants for pollinators

C. Parasitic Plants "pursuing" Hosts

parasitic plants such as dodder are able to follow a "scent trail" to find their host

→ they grow toward host

D. Plants Competing for Resources

some plants, often desert plants or where resources are scarce secrete chemicals into the soil to prevent other plants from growing nearby

eg. creosote bush

E. Plant Defenses & Defensive Behaviors

plants must defend themselves from a variety of

pests: birds, insects, mammals, fungi, viruses, bacteria, roundworms

>200 known bacterial diseases of plants

→ symptoms: soft rots, leaf spots, blights, wilts, galls

>7600 viral plant diseases known

→ symptoms: stunted growth, leaf deformities, tumors

>2000 species of parasitic roundworms as well as other animal parasites

→ usually attack roots

>millions of herbivorous animals, especially insects and mammals that feed on plants

since plants can't actively avoid such confrontations they have developed a wide variety of mechanical and chemical defenses to protect themselves

Mechanical Defenses

eg. spines, hairs, tough surfaces, thorns, prickles, seed coat, etc

eg. some grasses have silica crystals in leaves to deter herbivores

causes cuts in humans

Plant Defensive Chemicals

plants produce 1000's of chemicals that are used for protection and defense

eg. Alkaloids (N containing cmpds) & Tannins

very bitter tasting chemicals

alkaloids

eg. nicotine, caffeine, quinine

tannins

eg. taste of tea, tartness of persimmons, some of the flavor of certain wines

most of these chemicals seem to be poisonous or even fatal to animals if ingested

both fungi and plants produce these compounds but mainly in only a few plant families

animals cannot make them

plants produce **alkaloids** that protect them against herbivores and pathogens

eg. poison ivy, nightshade

alkaloids are often localized in specific plant parts

eg. potato plants: leaves, fruits and skins of tubers (if exposed to light)

in potatoes some are concentrated in the skin of the potato

most are usually removed by peeling

→ cooking potatoes in their skin may cause these chemicals to move into the "flesh" of the potato

→ don't eat raw potato skins if green on inside

[Application]

in small doses, some alkaloids have medicinal properties

1000's of prescription and OTC medication

some are addictive &/or hallucinogenic in humans

eg. nicotine, cocaine, heroin

[Application]

tannins are widely used as stains, dyes, inks or tanning agents for leather

may be a link between high levels of exposure to certain tannins in foods and the workplace and some forms of cancer

but people who drink large amounts of green tea may be more protected from cancer due to other kinds of tannins

eg. Resins

mainly produced by conifers

defensive chemical that helps prevent fungal infections and insect damage

eg. Capsaicum

capsaicum (give peppers their fire) inhibits herbivorous mammals from eating the fruit

prevents certain fungi from infecting its seeds

eg. Some Protective Proteins

some plants produce proteins that inhibit digestion in insect gut and therefore cause the animal to eat less or to move to another plant

eg. many crop plants damaged by feeding insects send a message throughout the plant causing it to synthesize proteins that inhibit digestion in the gut of the insect

some plant chemicals are used to **communicate** to other plants of the same species

eg. corn plants release a volatile chemical when being eaten by caterpillars that attracts predatory wasps that parasitize the caterpillars that feed on them

plants can also detect chemicals produced by nearby herbivores

→ triggers them to produce more alkaloids to make leaves less palatable

Plant Hormones

many of the plant activities above are regulated by **hormones**

Hormone = chemical produced in one tissue or organ has its effect in another tissue or organ (**=target cell or organ**)

since plants are relatively large & complex they also need to have some way to coordinate and control these activities

→ make sure activities throughout the plant are timed properly

activities of complex organisms (plants & animals) can be coordinated by

→ **nerve impulses** (only in animals)

→ **hormones** (found in all kingdoms)

chemical controls is a common feature of all organisms

single celled organisms secrete chemicals that affect their environment and each other

eg. bacteria → colonial species → attraction
eg. mating → Paramecium
eg. repelling BG bacteria → toxins

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

multicellular fungi, simple plants and simple animals that lack an elaborate transport system
→ chemicals diffuse from cell to cell

or maybe carried by water if aquatic to other cells in same individual

organisms with vascular systems, higher plants and animals transport chemicals in fluid

in plants → phloem
in animals → circulatory system

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

Major Plant Hormones:

- A. Auxins**
- B. Gibberellins**
- C. Cytokinin**
- D. Ethylene**
- E. Abscissic Acid**

A. Auxins

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

1st plant hormone identified

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

today we have identified several important functions of auxins:

1. promotes phototropism

→ stems (shoots) bend toward light (=phototropism)

2. promotes geotropism

→ roots bends downward toward ground (away from light) (=geotropism)

has inhibitory effect on "down" side of root

3. promotes apical dominance

(=growth of a single main stem or trunk)

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

eg. pruning, pinching

snip off apical bud to get branching

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

5. leaf abscission (& fruit drop)

the loss of leaves or dropping of ripe fruit depend on changing levels of auxins on each side of the "abscission zone" at the base of the leaf or fruit

eg. in leaves **higher** auxin levels (in leaf vs stem) promote loss of leaves

eg. in fruits **lower** auxin levels (in fruit vs stem) cause fruit drop

eg. artificially applied auxins to fruit

→delay fruit drop and produce larger fruits

eg. 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

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

a. the dioxin in the mix was later found to cause:
>health problems

>incidence of some forms of cancer

>birth defects and stillbirths

b. over a third of the commercial and natural forests and 1000's of acres of farmland were destroyed

6. promotes adventitious root development

auxins also control the development of **adventitious roots**

→ treating stem with auxins promotes root development

eg. root stimulators are synthetic auxins used to stimulate root development on cuttings for asexual propagation

B. Gibberellins

gibberellins are produced mainly in developing leaves, shoots, roots and seeds

1. promotes stem elongation

causes sudden & excessive lengthening of stem

eg. when biennial plants such as lettuce and cabbages, or yuccas, century plant send up long flower stalks(=bolt)

dwarf plants such as in sub arctic, lack gibberellins

→ when gibberellin is added they grow to normal heights

eg. most grape growers spray vines with gibberellins to increase length of branches between fruit clusters (more air, fewer fungal infections)

→ produces larger, healthier grapes

2. gibberellins may also be involved in plant movements and flowering

C. Cytokinins

produced in roots and move throughout the plant

1. promote cell division & differentiation

they must be present in cells for them to divide

→plant cells grown in culture without it will enlarge enormously but will not divide until cytokines are added

2. delays senescence & aging

plants receive a continuous supply of cytokines from roots

→ when cut they age and die rapidly

eg. if sprayed on cut leaves and stems they will remain green longer while unsprayed leaves will turn yellow and die

D. Ethylene

a gas

1. promotes fruit ripening

as fruit ripens it produces ethylene which accelerates the process

eg. "one rotten apple spoils the lot"

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)

E. Abscissic Acid

[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 abscissic acid

2. promotes seed dormancy

seeds have a high concentration of abscissic acid and cannot germinate until these levels are reduced

→ a mutant corn unable to make abscissic acid germinates on the ear

spring rains wash out the abscissic acid allowing seed to germinate

eg. soak seeds before planting

3. acts as plant stress hormone

protects cells from drought, freezing, salination