

How Do Herbicides Actually Kill Plants?

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In Today's Class

- What is Herbicide Mode of Action (MOA)?
- Some Commonly-Used MOAs
- Herbicide Translocation

Biosynthesis in a Cell is Like an Assembly Line

- In an assembly line, each worker **adds something**, eventually leading to a **finished product** at the end of the line
- In a cell, **enzymes** are the assembly line **workers**, each adding or removing little bits to a molecule
- At the end of the line, a finished **protein** or **fatty acid** or **complex molecule** results



The Process is Like a Flowing River

- In a healthy plant, biosynthesis proceeds in an orderly fashion from a **precursor molecule** to a **finished product**
- What happens if something interrupts a river's smooth flow?
- Something like a dam?



The Process is Like a Flowing River



Herbicides Normally Target Enzymes

- If downstream flow from the precursor molecule stops, **no product is formed**
- But the precursors keep coming, leading to a **buildup of those molecules**
- Both results are **bad for the weed!**



With That in Mind, Here Are Two Terms to Know

- **Mode of Action:**

- The overall manner in which a herbicide affects a plant **at the tissue or cellular level**
- Usually defined by a **specific enzymatic (biochemical) pathway** affected (can be broad or narrow)
 - **Photosynthetic inhibitor** (Princep)

- **Mechanism of Action:**

- Usually references the **specific molecular site** in the plant (inhibitors of **5-enolpyruvylshikimate-3-phosphate synthase** [EPSPS] = Glyphosate)

Herbicide Efficacy

- To be effective, a herbicide must:
 - Have adequate contact with the plant
 - Be absorbed into the plant
 - Move to the site of action (without deactivation)
 - Accumulate to a toxic level at the site of action

Synthetic Growth Regulator Herbicides

Growth Regulators in Plants

Auxins	Influences cell enlargement, cell differentiation, bud formation, root initiation, and causes apical dominance
Gibberellins	Initiates mobilization of storage materials during seed germination and causes stem elongation and bolting in biennials
Cytokinins	Counters auxin effects, influencing cell division, shoot formation, and budbreak
Abscissic Acid	Mediates bud dormancy and formation of bud scales
Ethylene	Ethylene affects cell growth and shape, fruit ripening, and (with ABA) regulates leaf fall

Synthetic Growth Regulators

- Group 4 herbicides:
 - Phenoxy Acetic Acid
 - 2,4-D (lots of trade names), 2,4-DB, and MCPA
 - Benzoic Acid
 - Dicamba (Banvel, Clarity)
 - Pyridine or Picolinic Acid
 - Clopyralid (Transline), Triclopyr (Garlon, Renovate), Picloram (Tordon), Fluorxypyr (Starane), Aminopyralid (Milestone), Aminocyclopyrachlor (Perspective)

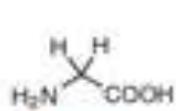
Synthetic Growth Regulators

- Mimic natural plant growth regulators (**auxin**)
 - Disrupt hormone balance and protein synthesis
 - Epinasty (abnormal **twisting and bending**)
 - New growth is affected
- **Broadleaf weeds** are affected
 - Can injure grass; depends on stage and rate
- Primary uptake through foliage
 - Move in xylem and phloem
 - Soil residual activity

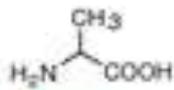
2,4-D Applied to Tomato



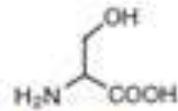
Amino Acid Synthesis Inhibiting Herbicides



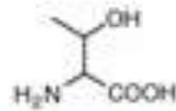
Glycine



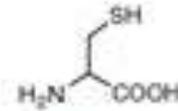
Alanine



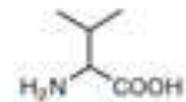
Serine



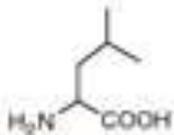
Threonine



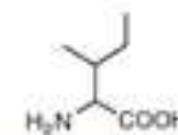
Cysteine



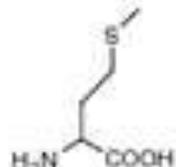
Valine



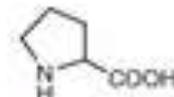
Leucine



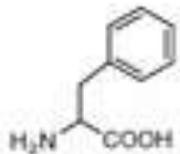
Isoleucine



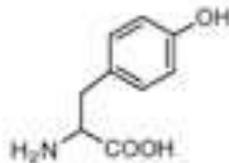
Methionine



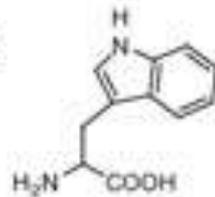
Proline



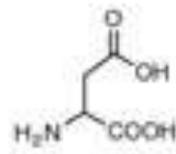
Phenylalanine



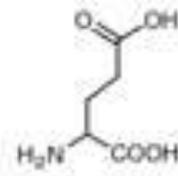
Tyrosine



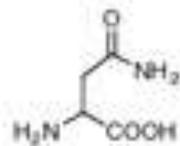
Tryptophan



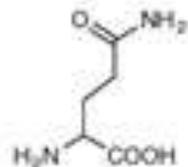
Aspartic Acid



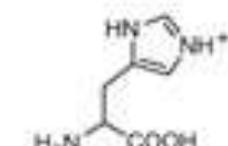
Glutamic Acid



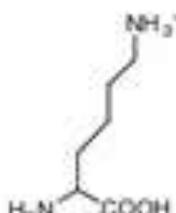
Asparagine



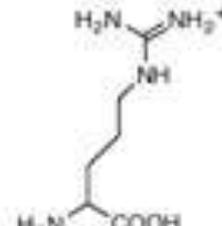
Glutamine



Histidine

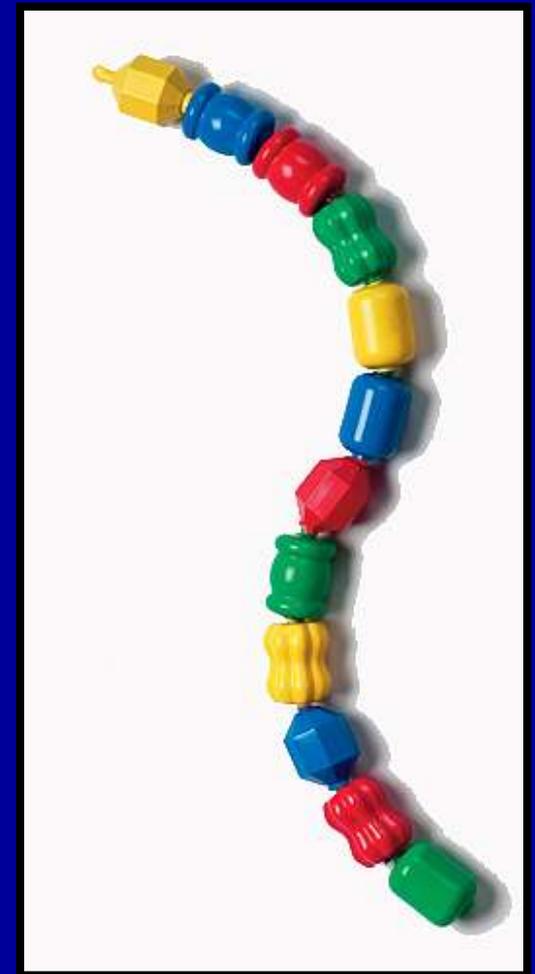


Lysine

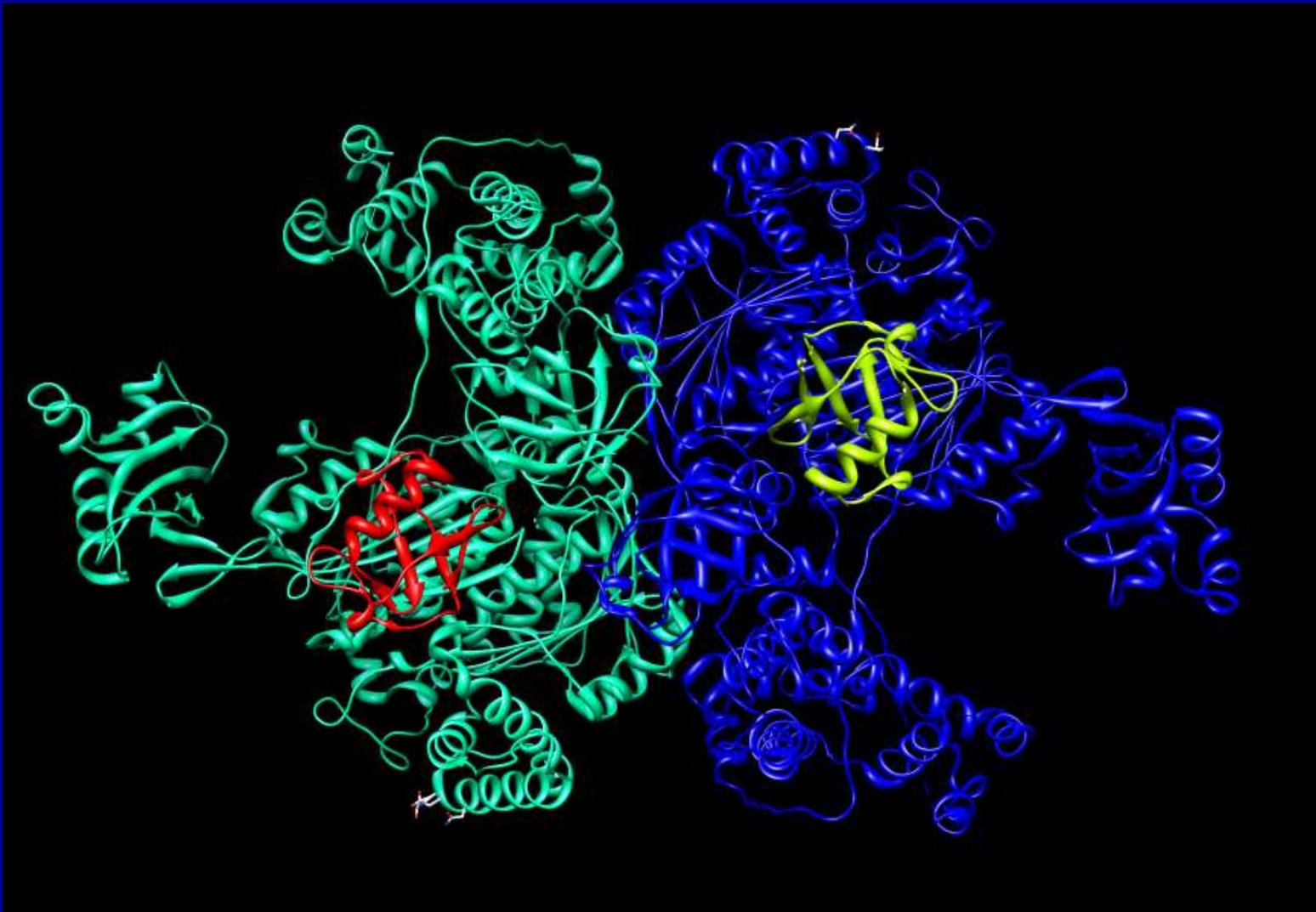


Arginine

The 20 Most Common Amino Acids

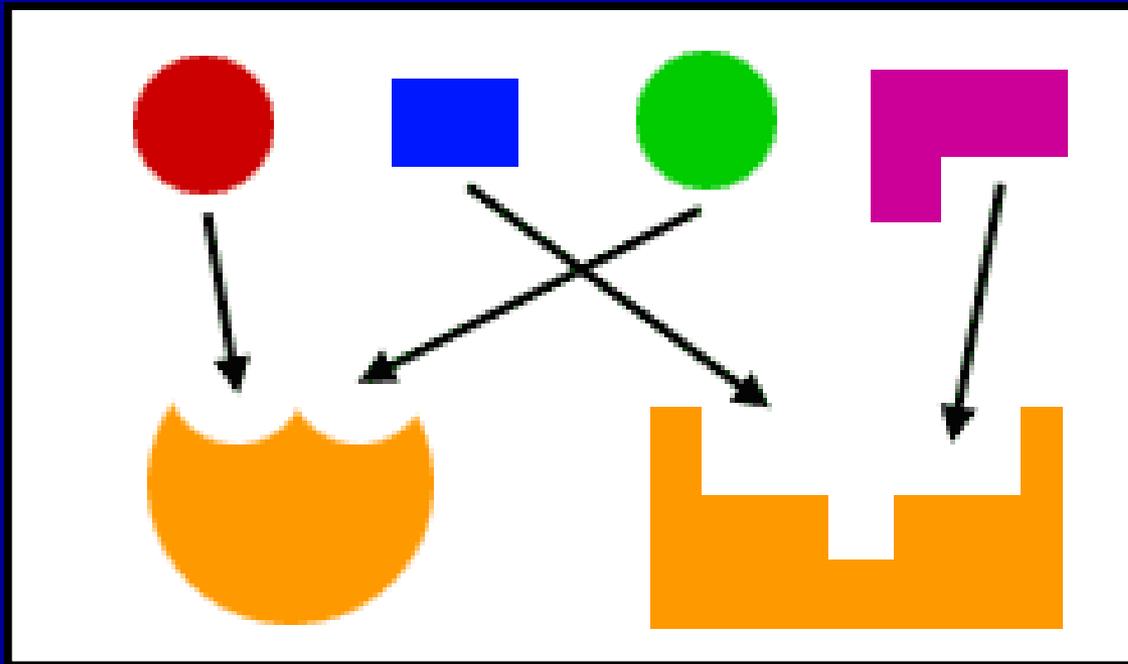


Proteins (structural and enzymes) are made up of **amino acids** linked together in **long chains**



3-D representation of a protein showing **folders and bends** in the amino acid chain

Various Substrates

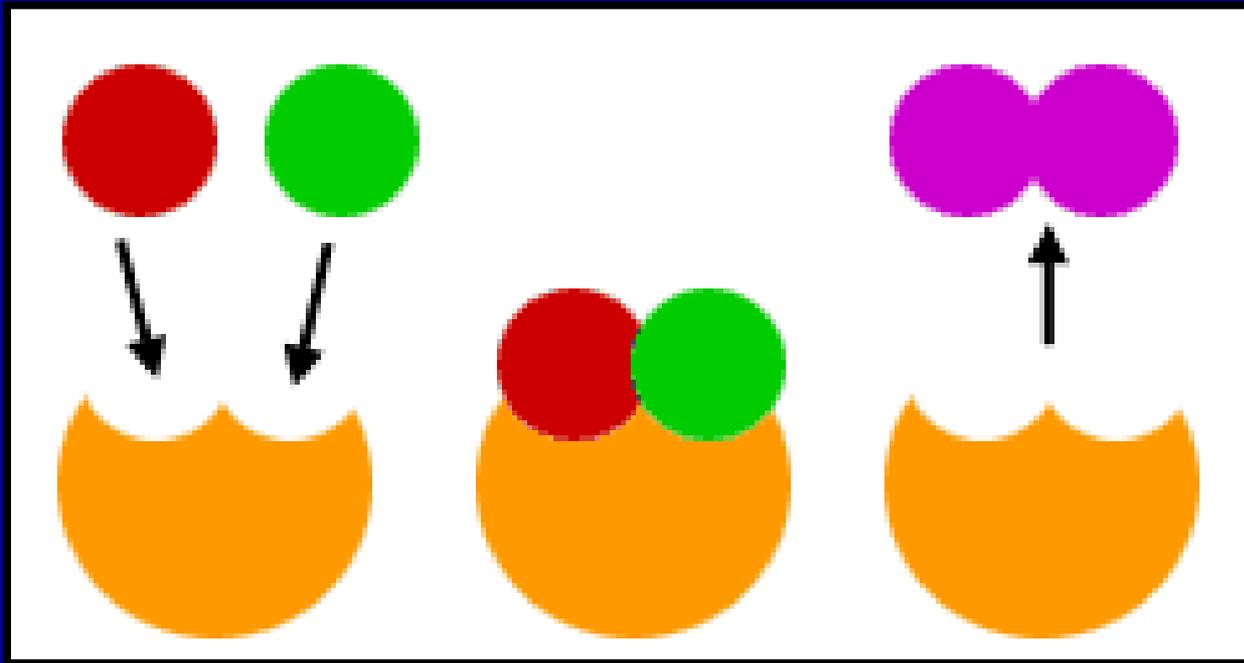


Enzyme A

Enzyme B

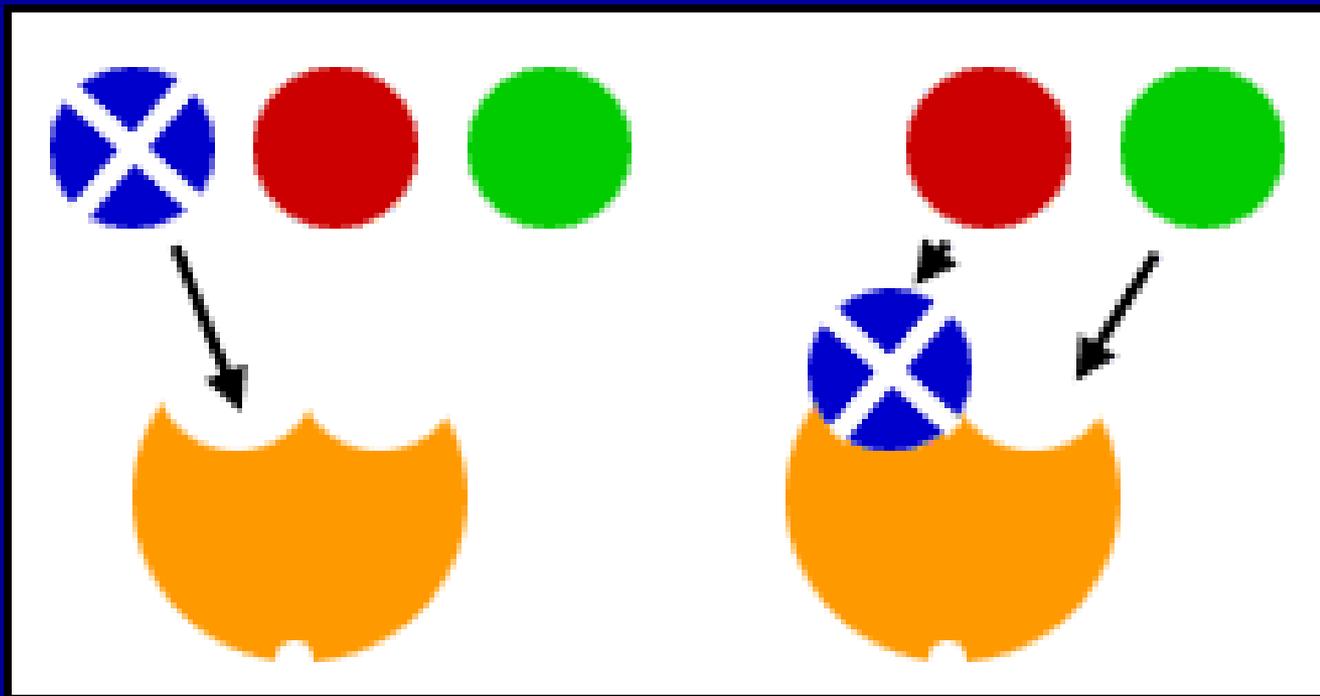
Enzymes are very specific as to which **substrates may bind** to their active sites and which **products they form**

Substrates bind to specific sites on Enzyme A



Substrates are combined into a single product by Enzyme A

Herbicide binds to Enzyme A



Substrates can no longer bind to Enzyme A, so product is not formed

Amino Acid Synthesis Inhibitors

- Two Mechanisms of Action:
 - ALS inhibitor (**Group 2**)
 - **Sulfonylurea**
 - Chlorsulfuron (**Telar, Glean**), Metsulfuron (**Escort**), Sulfometuron (**Oust**), Rimsulfuron (**Matrix**), Halosulfuron (**Sandea**), etc.
 - **Imidazolinones**
 - Imazapic (**Plateau**), Imazapyr (**Arsenal, Habitat**), Imazamox (**Raptor, Clearcast**), etc.
 - EPSPS inhibitor (**Group 9**)
 - **Amino Acid Derivative**
 - Glyphosate (**Roundup, Rodeo**, etc.)

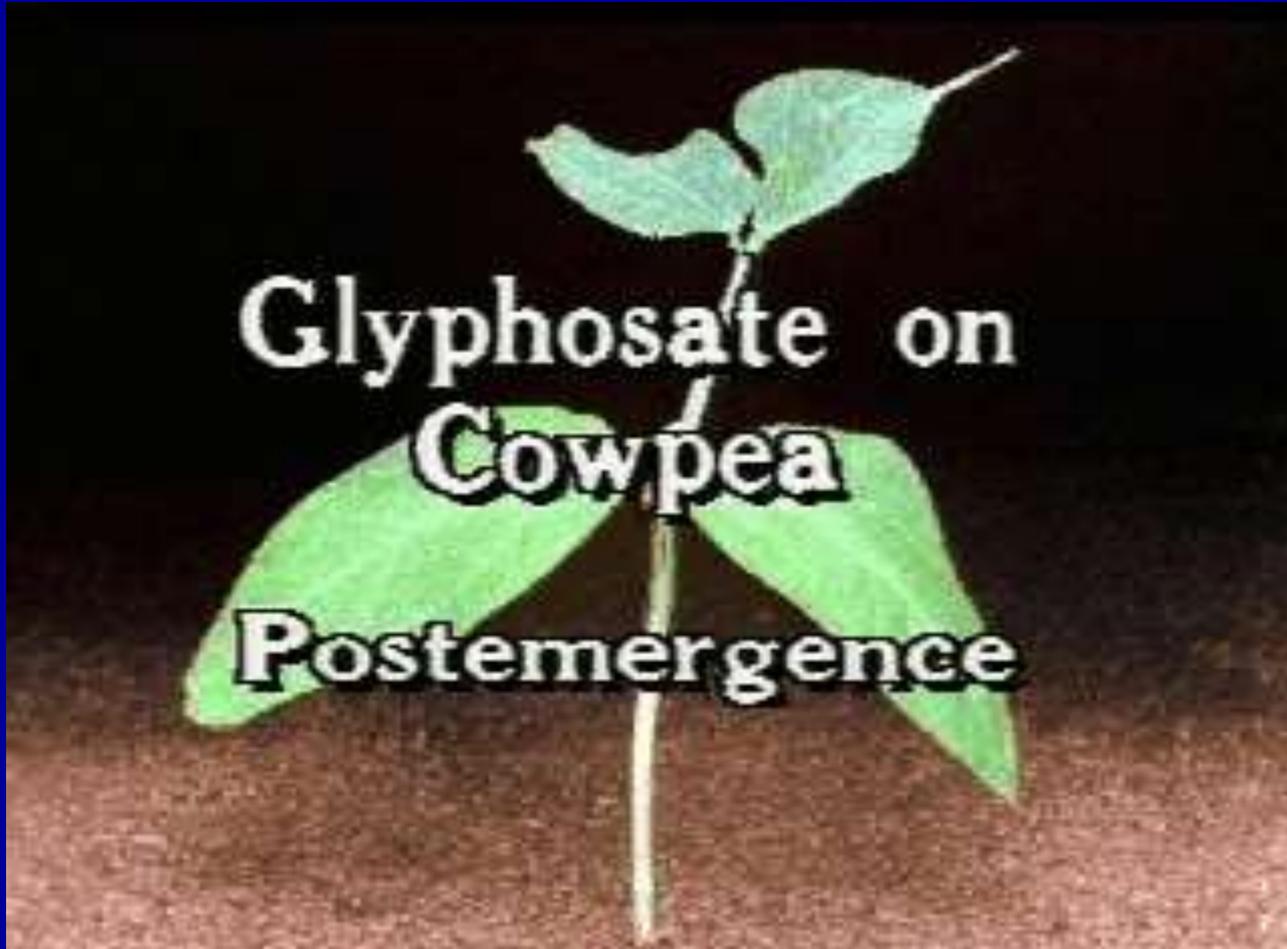
Amino Acid Synthesis Inhibitors

- Act on enzyme to **prevent amino acid production**
 - Protein is necessary for normal plant growth
- Active on broadleaf or grass weeds
 - Often provide excellent **perennial weed control**
- **Foliage** and **root** uptake
 - Move in xylem and phloem
- Injury symptoms slow (1 to 3 weeks)
 - **New foliage first**
 - **Stunting, yellowing or purpling**

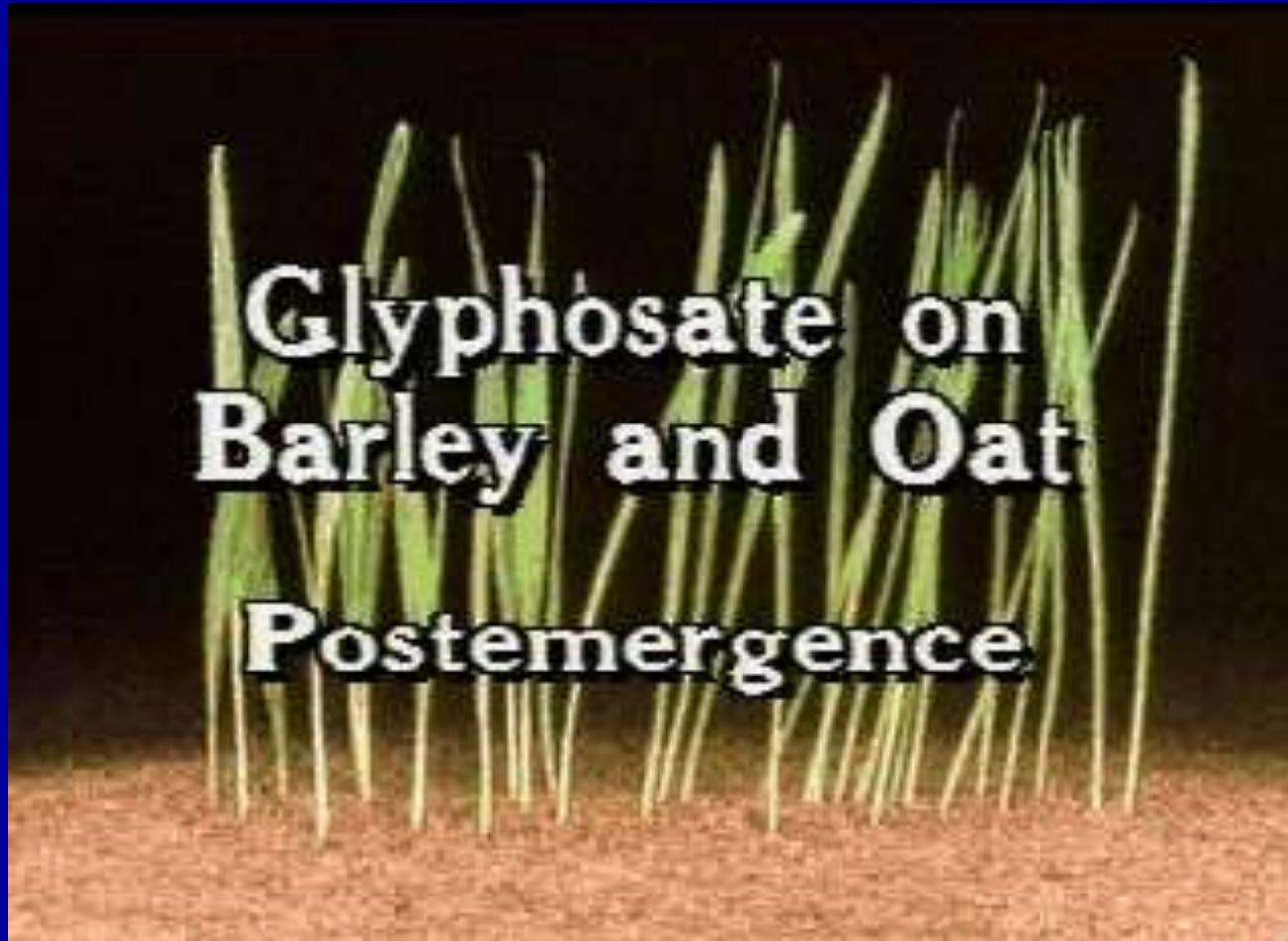
Chlorsulfuron (Glean) on Bean



Glyphosate (Roundup) on Bean

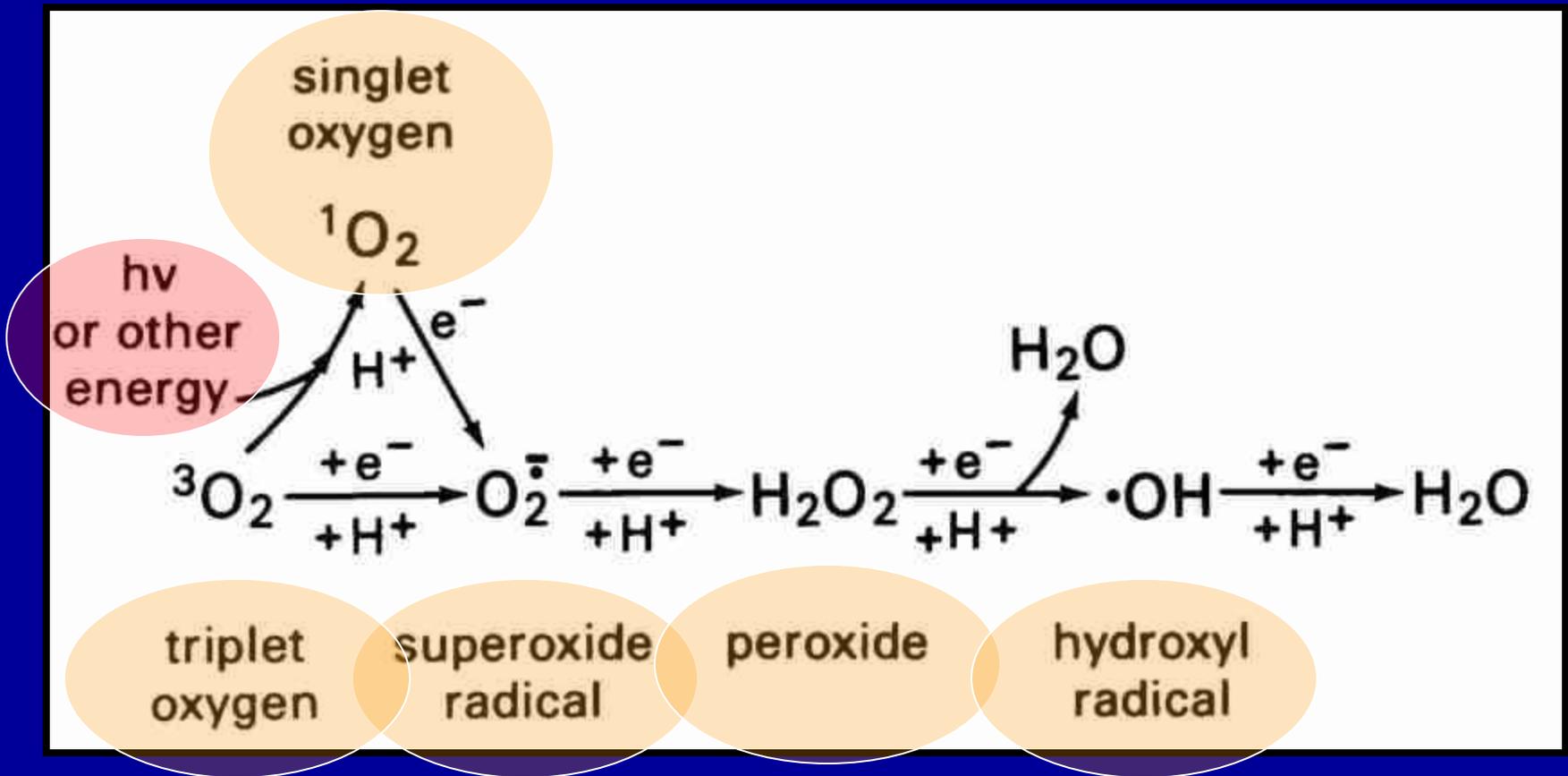


Glyphosate on Barley & Oat



Cell Membrane Disrupting Herbicides

Membrane disruptor herbicides **steal electrons** from chloroplasts **during photosynthesis**, creating singlet and triplet oxygen, peroxide, and superoxide radicals



Cell Membrane Disruptors

- Dicarboximide (inhibit PPO, Group 14)
 - Flumioxazin (Chateau, Payload, SureGuard)
- Pyrazole (inhibit PPO, Group 14)
 - Pyraflufen (Vida)
- Bipyridyliums (inhibit Photosystem I, Group 22)
 - Paraquat (Gramoxone) and diquat (Reglone, Reward)

Cell Membrane Disruptors

- Group 14 herbicides
 - Preemergence and postemergence activity
 - Primarily affect broadleaf weeds
- Group 22 herbicides
 - Postemergence, contact herbicides
 - Activated by sunlight
 - Symptoms often in 1 to 2 hours, so there is rapid burn-down
- For annual weed control; perennials will re-grow

Paraquat on Bean

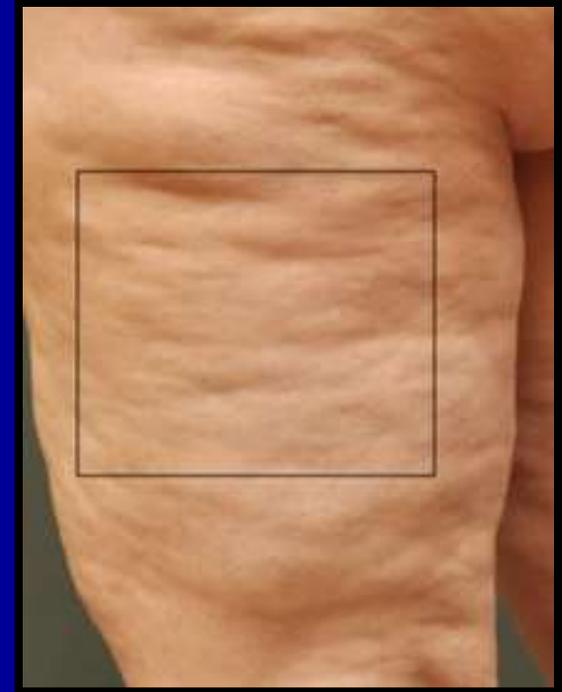


Cellulose Synthesis Inhibiting Herbicides

What is Cellulose?

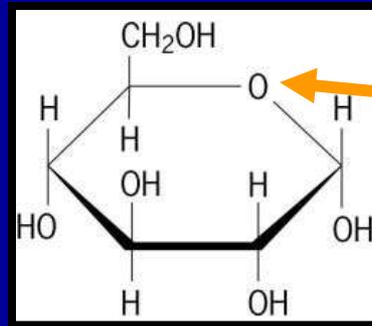
What is Cellulose?

- No, not cellulite



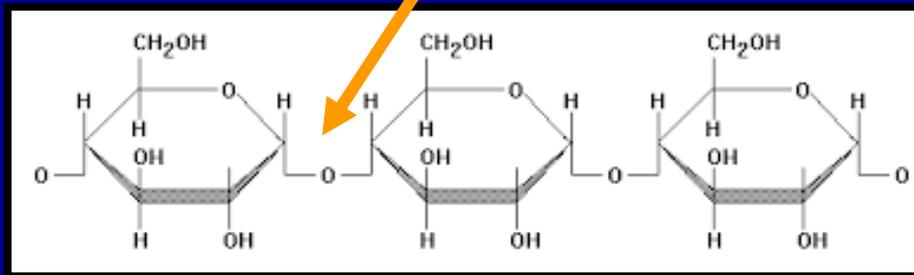
What is Cellulose?

- **Cellulose** is a long chain of linked glucose molecules

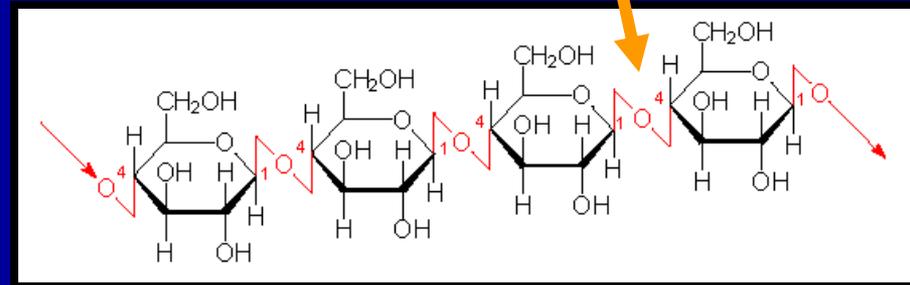


Glucose is a simple 6-carbon sugar

- Starch results from one kind of **glucose linkage** (α), cellulose from a second (β)



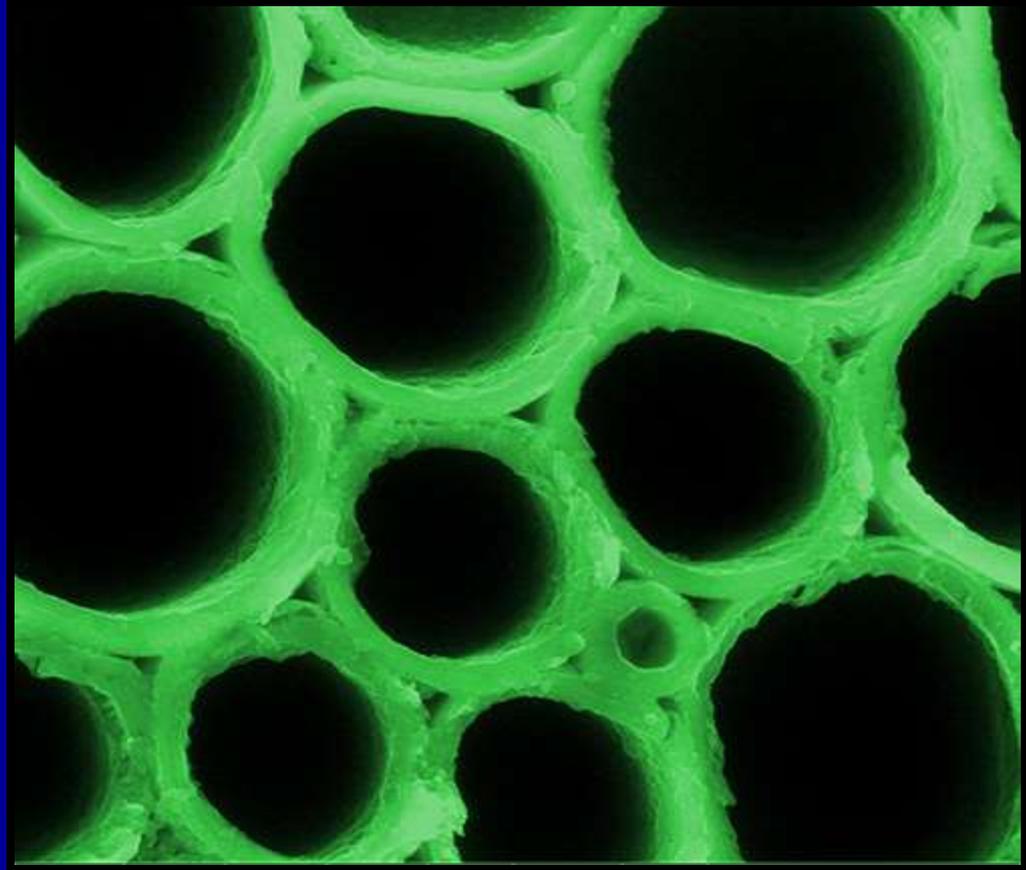
Starch



Cellulose

What is Cellulose Good For?

- Cellulose is a major constituent of **cell walls**
- Unique to plant cells and certain microbes
- If a plant can't make cellulose, it **can't manufacture cell walls**



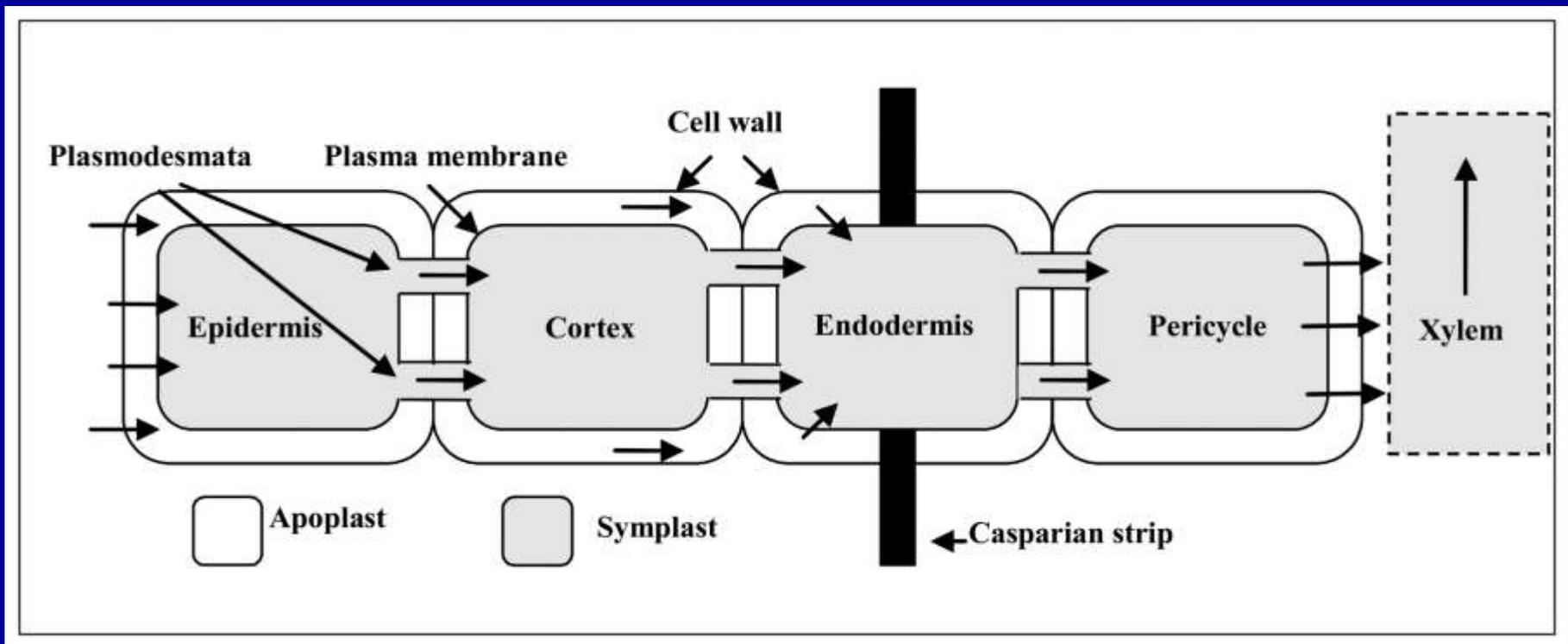
Cellulose Synthesis Inhibitors

- Nitrile (Group 20):
 - Dichlobenil (Casoron)
- Amide (Group 21)
 - Isoxaben (Gallery, Snapshot)
- Alkylazine (Group 29)
 - Indaziflam (Alion, Esplanade, Specticle)

Cellulose Synthesis Inhibitors

- Most active in **cool soils**
- Active on developing roots and shoots
 - Stop **cell division** by limiting the plant's ability to form **cell walls**
- Controls mostly **annual weeds**, but **Casoron** also suppresses many **perennial species**
- **Specticle** and **Gallery** only have PRE activity
- **Casoron** and **Specticle** have a **long residual**

Herbicide Translocation

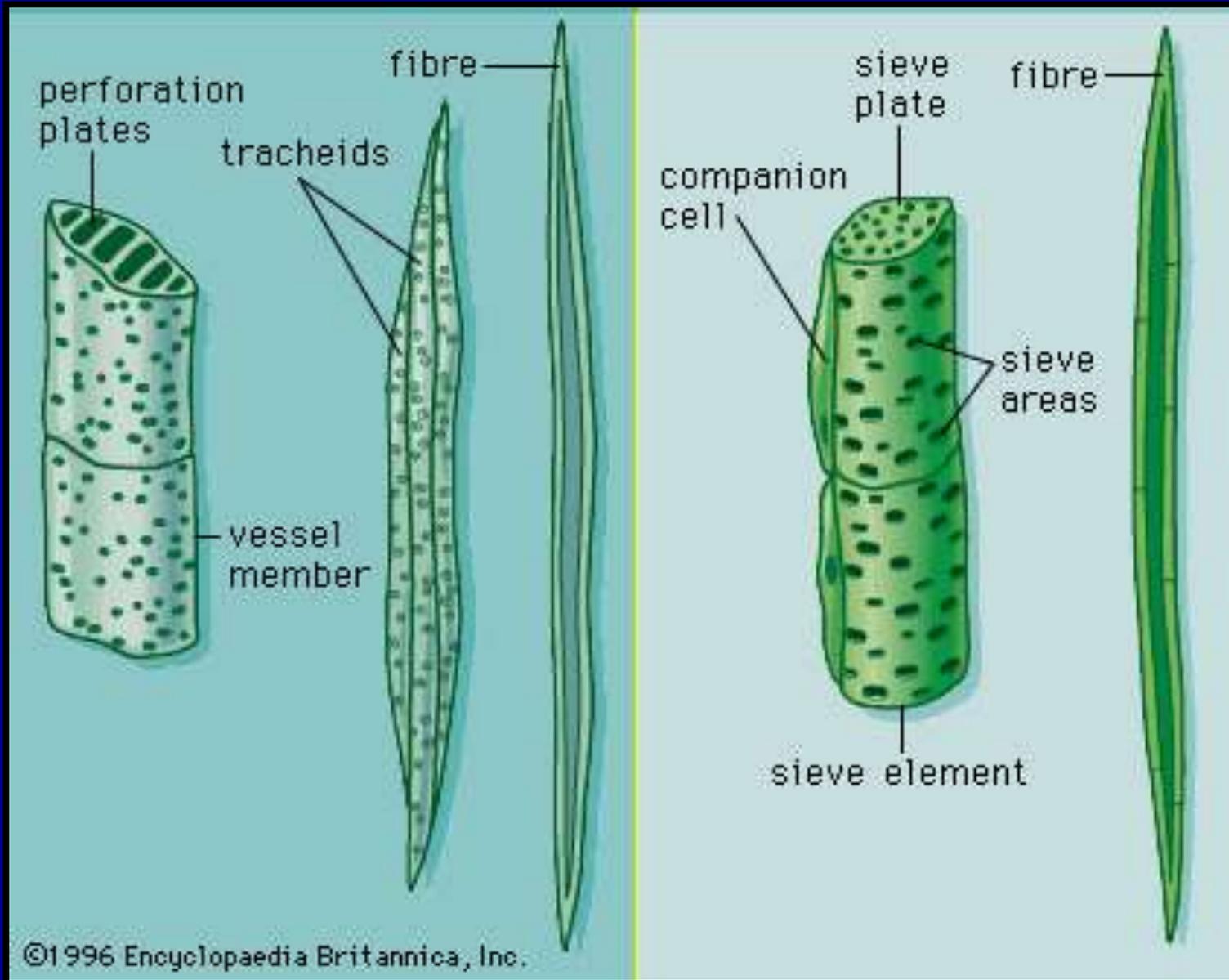


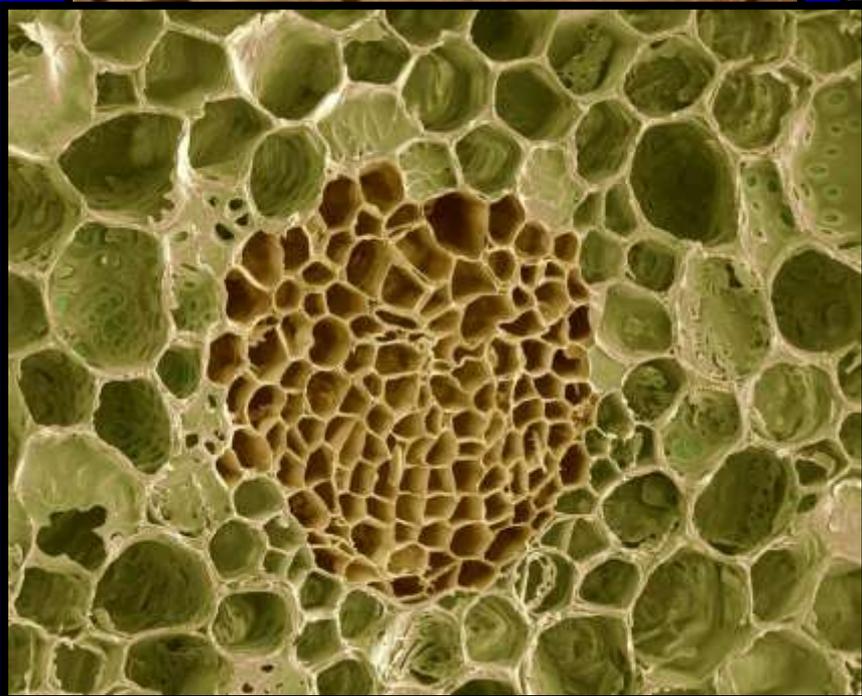
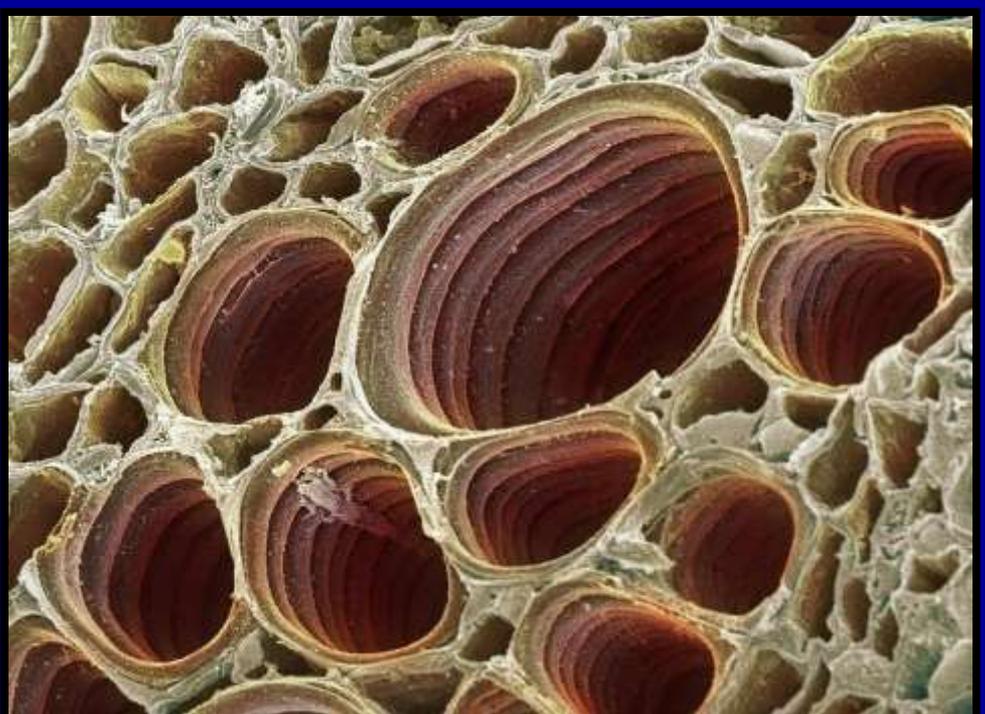
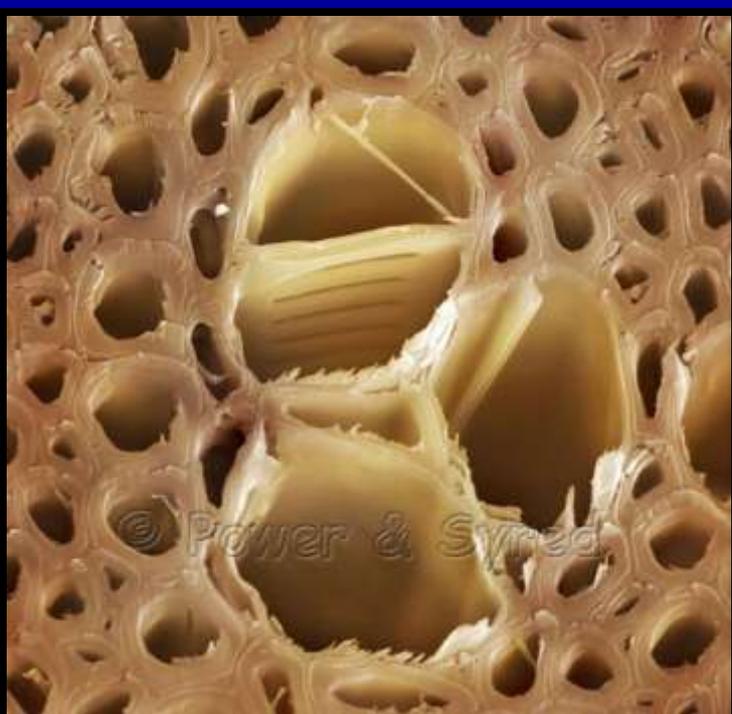
Interconnected Tubes

- Organs of vascular plants contain two types of cells that form an **internal network of tubes**, similar to the network of arteries, veins, and capillaries in animals
 - **Xylem cells** grow and die, and when dead retain their shape and fill with water to form a **continuous chain** from **root to leaf**, though **stems** and **rhizomes**
 - **Phloem cells** are still living, with sugars moving from cell to cell

Xylem

Phloem





Xylem Cells

- Water **evaporating** from **leaf surfaces** into the air (transpiration) forms a **slight vacuum** in the xylem vessel elements at that end of the tube
- Water is then **“pulled”** into the **partial vacuum** from connected xylem cells, causing an **upward movement** from root to shoot
 - Minerals and dissolved compounds in the water **“go along with the flow”** toward the leaves
- Although some water is used for **cell enlargement** and **photosynthesis**, almost all water in xylem cells is **lost via transpiration** to the atmosphere, powering the system

It's A Sweet World

- All **living** plant (and animal) **cells require energy** to properly function and remain living
 - This energy comes from **simple sugars** (mostly glucose and fructose, which together form sucrose)
 - Energy is released as the living cells break the sugars apart (a process known as **respiration**)
- When a plant has green leaves, water, CO₂, and sunlight, **sugars** are actively being created via **photosynthesis**. **But the plant has a problem:**
 - Roots/rhizomes do not photosynthesize (it's dark in the soil!), but they require energy to stay alive and grow
 - The sugar is up in the leaves
 - **What to do?**

Translocation

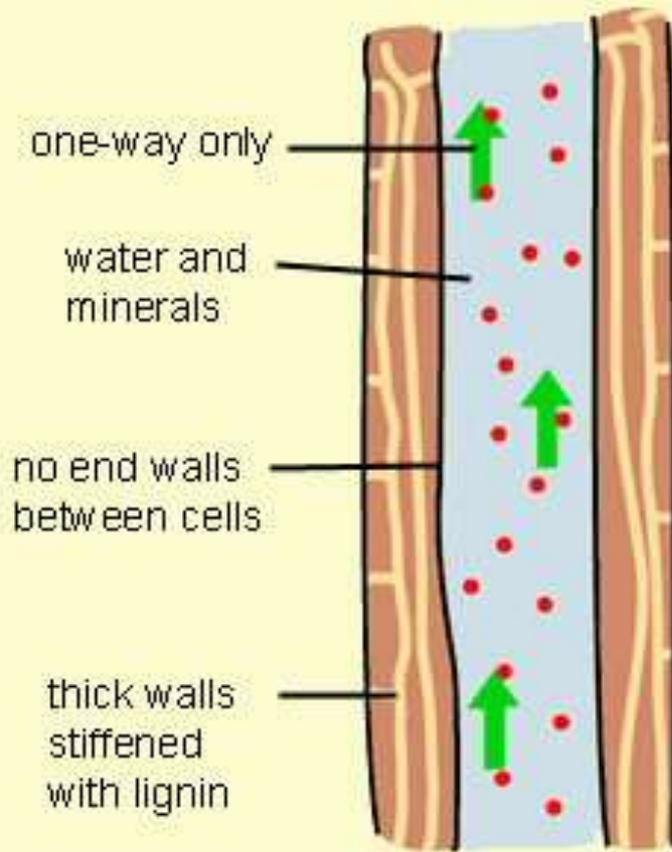
- Sugars are “loaded” into phloem cells in the leaves (source) where plenty of sugar is present
- Sugars then move to where they are “unloaded” where energy is required (sink)
- In summer, sugar molecules that are not immediately used by root/rhizome cells are converted into starch and other complex carbohydrates for storage
 - Remember, one of the key function of roots and rhizomes is for storage of photosynthates

But Wait! There's More!

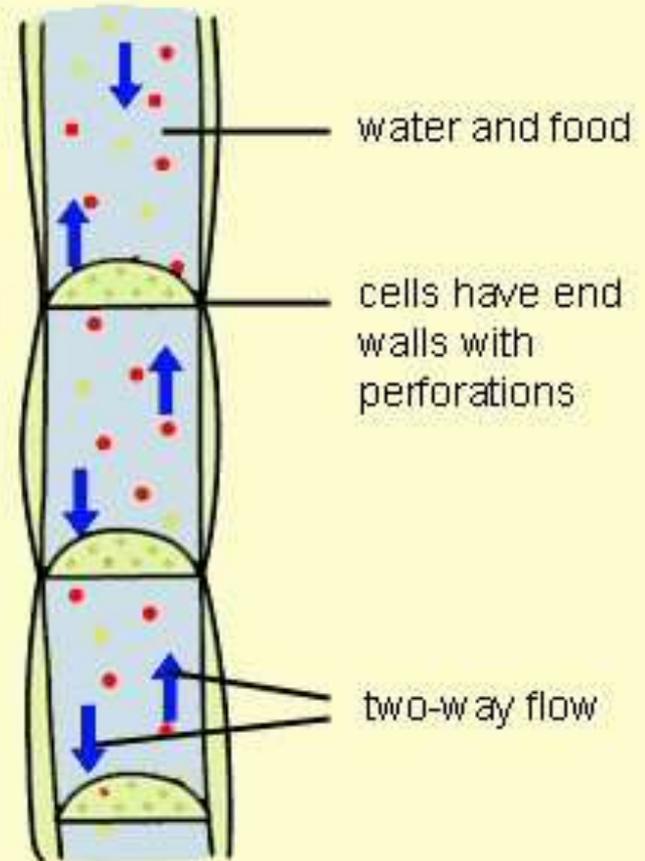
- When a plant **does not have leaves** (such as in winter), the cells of a biennial/perennial plant still have **a need for energy**
- If there is **no active photosynthesis** occurring (such as in early spring), phloem works in the **opposite direction**
 - Starch is broken down in **rhizomes/roots** (source) to form those same simple sugars
 - Sugar is then loaded back into the phloem and moves to the **crown or buds or root/shoot tips** (sink) that are waking up after winter
- **What powers all this sugar moving around?**

Phloem Cells

- Sugars flow in phloem mostly due to the **concentration gradient** between **source and sink**
 - Think of a sugar cube in your coffee
 - The **sugar dissolves**, then moves around in the cup **by diffusion** until it is evenly distributed in the coffee
 - In a similar way, sugar moves from an area in the plant **where there is a lot of sugar** (source) to an area in the plant **where there isn't as much sugar** (sink)
- Sinks in vascular plants include regions of rapidly dividing and growing cells (**meristems**), **flowers**, **fruits/seeds**, and **roots/rhizomes**



Xylem



Phloem

Xylem-Mobile Herbicides

- Absorbed by roots with **soil water**
- The herbicides move along with the water from **roots** to **shoots and leaves**
- As **water evaporates**, herbicides remain behind **in the leaves**
 - Many of these products are **photosynthetic inhibitors**, so the leaf is a great place for them to accumulate

Herbicide Translocation From Foliage

- Most foliar-applied herbicides move in **phloem**
 - Some can also move in **xylem**, but it's difficult for them to "go against the flow" **from leaves to roots/rhizomes**
- Herbicides are off-loaded with **sugars at the sinks** (meristems, flowers, fruits/seeds, roots/rhizomes)

Factors Affecting Herbicide Uptake and Translocation

Dust, Wheels, and Herbicides

- Recall that many herbicides **bind with soil**, so dust on plant foliage ties up the herbicide and **reduces activity**
- POST herbicides **don't translocate** as well in weeds that are damaged by wheels



Spray Volume and Herbicides

- Lower spray volumes sometimes **work better** than higher volumes (at least with glyphosate)
- It's not clear why...
 - Smaller nozzles = smaller droplets = better coverage?
 - Lower volumes of hard water = fewer cations to bind with herbicide molecules?
 - Something else?



Climatic Influences



- **Temperature**
 - Cold or heat-stressed plants don't translocate herbicide as well
 - Herbicide activity changes
- **Humidity**
 - Higher humidity may improve herbicide penetration and plant receptivity

Optimize Herbicide Applications!

- Spray at the proper **stage of growth**
- Perennials
 - **Bud stage**
 - **Late fall**
- Biennials
 - **First-year rosettes**
- Annuals and seedlings
 - PRE applied **prior to seed germination**
 - POST applied as early as possible **after seed germination is complete** for the year





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