Lecture Schedule (middle third)

18 Feb KB - Fungi, Ch31
23 Feb KB - Prokaryotes & Protists, Ch28&29
25 Feb KB - Plant Diversity, Form, Function, Ch30&40
2 Mar KB - Plant Form and Function, Ch36&37
4 Mar KB - Plant Function, Ch38&39
9 Mar KB - Plant Ecology, Ch50,52,53
11 Mar KB - Ecology, Ch50,52,53
13-21 Mar Spring Break
23 Mar KB - Biology of the Galapagos
   Wikelski 2000 and http://livinggalapagos.org/
25 Mar KB - Part 2. Discussion and Review.
30 Mar KB - EXAM 2

Plants: Nutrition Etc.

How do plants get nutrients they need?

Usually from soil through roots.
A few interesting exceptions...

http://www.youtube.com/watch?v=ymLqQny25g#feature=related

Nutritional Requirements

- early 1600s, classic experiment by van Helmont
- mass of a growing plant comes from
  - soil?
  - water?
  - (elsewhere?)

In addition to carbon dioxide and water, plants require essential nutrients.
Most nutrients are available as ions dissolved in soil water and are taken up by roots.
Nutrient absorption occurs via specialized proteins in plasma membranes of root cells. Most plants also obtain _______ or phosphorus from ________ associated with their roots.
Nutritional Requirements

- early 1600s, classic experiment by van Helmont
- mass of a growing plant comes from soil?
- mass of a growing plant comes from water?
- [Most of the mass of the tree actually comes from ______ in the atmosphere]

Which Nutrients Are Essential?

- Classified based on whether from water &/or carbon dioxide versus from ___
- Essential nutrients available from H₂O or CO₂ are ______ and ______. They make up 96% of the plant.
- Soil elements can be divided into macronutrients and micronutrients.

Which Nutrients Are Essential?

- Macronutrients are the building blocks of nucleic acids, proteins, carbohydrates, phospholipids, and other key molecules required in relatively large quantities. They are
  - nitrogen (N)
  - potassium (K)
  - calcium (Ca)
  - magnesium (Mg)
  - phosphorus (P)
  - sulfur (S).
- An __________ nutrient: required for both normal growth and reproduction and for a specific structure or metabolic function.
- There are 17 essential nutrients for most vascular plants.
Which Nutrients Are Essential?

- Limiting nutrients are macronutrients that commonly act as limits on plant growth. ___ and ___ are often limiting nutrients.

Micronutrients are required in very small quantities. Rather than acting as components of macromolecules, they usually function as cofactors for specific enzymes. Examples include:
- iron, zinc, boron, copper, and nickel.

studying nutritional deficiencies

- Hydroponic growth takes place in liquid cultures, without soil, so the availability of nutrients can be precisely controlled.

Experiment

**Prediction:** The copper-deficient plant will grow less than the normal plant. Prediction of null hypothesis: Both plants will grow the same.

Results: Copper!

Conclusion: Copper deficiency leads to poor growth. All tissues appear to be affected adversely.
Soil

- **Weathering**—the forces applied by rain, running water, and wind—begins the process of building soil from solid rock.

- Particles derived from rocks are the first ingredient in soil. As organisms occupy the substrate, they add dead cells and tissues. This organic matter is called ______.

- **Organic + Inorganic = Mature Soil**

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**What Factors Affect Nutrient Availability?**

- **Cations** tend to bind to soil particles, while **anions** stay in solution. **(Leaching: loss of nutrients via washing)**.

- **Soil pH** (lower pH ~ more H+)
  - **acidic** (low pH) or **alkaline** (high pH)

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Root Hairs Increase the Surface Area Available for Nutrient Absorption

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**Mechanisms of Nutrient Uptake**

- Plant cell walls can be **permeable**: to ions, small molecules, and some large molecules.

- Membrane proteins allow only specific ions to cross the plasma membrane: **highly selective**
Establishing and Using a Proton Gradient

- Root-hair cells have **proton pumps** (H⁺-ATPases) in their plasma membranes that move nutrients into the cell against a strong concentration gradient.

Ions Enter Roots along Electrochemical Gradients Created by Pumps

Cations Enter Roots via

- Channels

Anions Enter Roots via

- Cotransporters

Cation vs Anion Nutrients

- **Anions** easier to get than cations
  - But anions can leach out of sandy soils
  - Anions better retained in clay soils

- **Cations** often bound to organic or inorganic soil particles

- **Cation**
  - H⁺ (proton) for Mg⁺ or K⁺ or Ca⁺ etc.
  - Plants facilitate by pumping H⁺ out of root hairs
Nutrient Transfer via Mycorrhizal Fungi

- Vast majority of plants take up nutrients through their root hairs.
- But, most need more nitrogen and phosphorus.
- Help from fungi that live in close association with their roots.
- These fungi are called mycorrhizae.

Not all soil ions are "good" for the plant

In Salt-Tolerant Plants, an
Concentrates Sodium in Vacuoles

(a) In the tonoplast, antiporters send H⁺ out and Na⁺ in.

Some species of plant have specialized methods of obtaining nutrients, including associations with nitrogen-fixing bacteria, parasitism, and carnivory.

Nitrogen Fixation

- Plants and other eukaryotes cannot use N₂ from the atmosphere.
- However, some are able to absorb N₂ from the atmosphere and convert it to ammonia, nitrates, and nitrites in a process called nitrogen fixation.

Nitrogen Fixation

- Such bacteria often take up residence inside plant root cells.
- For example, members of the bacterial genus Rhizobium associate with plants in the pea family (legumes).
- Rhizobia (Rhizobium species and close relatives) are found in nodules on the roots of legumes and provide the plant with ammonia in return for sugar and protection.
In Some Plants, Roots Form Nodules where Nitrogen-Fixing Bacteria Live

Nutritional Adaptations of Plants

• Most plants use proton pumps as a mechanism for importing nutrients from the soil and/or acquire nutrients from symbioses.
• In addition, 99% of plants make their own sugars.
• Some plants don’t follow these rules, some appear to live on:
  1) some 2) others, some catch 3)

Epiphytic Plants

• Epiphytes are plants that are adapted to grow in the absence of soil. They often grow on leaves or branches of trees.
• They absorb most of the water and nutrients they need from rainwater, dust, and particles that collect in their tissues or in the crevices of bark.

Epiphytes Are Adapted to Grow in the Absence of Soil

Parasitic Plants

• Most parasitic plants make their own sugars through photosynthesis and tap into the vascular tissue of their hosts for water and essential nutrients.
• Some plant parasites are nonphotosynthetic and obtain all their nutrition from the host.
• There are at least 3000 species of parasitic plants

Some Plant Parasites Tap into the Xylem Tissue of Their Hosts

Mistletoe
Carnivorous Plants

- Carnivorous plants use modified leaves to trap insects and other animals, kill them, and absorb the prey's nutrients.

- Carnivorous species make their own carbohydrates via photosynthesis but use carnivory to supplement the nitrogen available in the environment, which is often lacking.

Sundews Have Modified Leaves with a Sticky Surface That Catches Insects

Plant Sensory Systems

(Freeman Ch39)
Plant Sensory Systems, Signals, and Responses

- Plants process information
- Environmental stimuli affect ability to grow and reproduce...
  - wavelength of light, photoperiod, time of day
  - gravity, mechanical stimulation (touch or wind)
  - disease-causing agents and herbivores.

Information Processing

- Monitor aspects of environment that affect fitness (survive & reproduce)
- Three steps:
  1. a receptor cell receives an external signal
  2. the receptor cell sends a signal to cells in another part of the plant
  3. responder cells receive the signal and change activity appropriately.

Signal Transduction

- Signals from environment received by specialized protein (for that function).
- Receptor proteins change shape in response to a stimulus. This causes the information to change form—from an external signal to an intracellular signal.
- This process is called

Signal transduction in a receptor cell often results in the release of a _____ that carries information to responder cells.

A few examples...

When sensory cells receive a stimulus, they transduce the signal and respond by producing hormones that carry information to target cells elsewhere in the body.

Hormones produce a response by acting on target cells.
**Blue Light: The Phototropic Response**

- Plants sense and respond to specific, narrow range of wavelengths.
- Any directed movement by an organism toward light is called ________.
- Plants exhibit a phototropic response only to blue wavelengths.
- Why blue light?

**Photosynthesis**

Chlorophyll a and b Absorb Most Strongly in the Blue (and Red) Parts of the Visible Spectrum

![Chlorophyll absorption graph](image)

**Auxin: Phototropic Hormone**

- The sensory and response cells in phototropism are not the same. Blue light is sensed at the tip of a coleoptile (protected shoot) and info is then transmitted to lower cells.
- Auxin (a hormone) is produced at the tip of the coleoptile, is transported to the area of bending, and acts as a signal...
- Auxin promotes cell _______ in the shoot.

**Photoperiodism & Flowering**

- Flowering in response to changes in day length—triggered by red/far-red light.
- **Photoperiodism** is any response by an organism that is based on ________, the relative lengths of day and night.
- In plants, the ability to measure photoperiod is important because it allows the plant to respond to seasonal changes in climate and the correlated availability of resources and pollinators.

**Different Species Respond to Photoperiod in Different Ways**

![Photoperiod response diagram](image)
Youth, Maturity, and Aging: The Growth Responses

• Controlling growth in response to changes in age or environmental conditions (one of the most basic aspects of information processing in plants).

• Hormones play a key role in regulating

Cytokinins & Cell Division

• Cytokinins are a group of plant hormones that promote cell division.

• Cytokinins are synthesized in root tips, young fruits, seeds, growing buds, and other developing organs.

• Cytokinins regulate growth by ______ the ______ that keep the cell cycle going. In the absence of cytokinins, cells arrest at the G₁ checkpoint in the cell cycle and cease growth.

Cytokinins Affect the Cell Cycle

Gibberellins and ABA: Growth and Dormancy

• Two types of hormones are responsible for initiating and terminating growth in plants in response to changes in environmental conditions:

  • gibberellins ______ growth, abscissic acid (ABA) ______ growth.

Gibberellins Stimulate Shoot Elongation

• Gibberellic acid (GA) is a gibberellin that appears to promote cell elongation and to increase rates of cell division in roots.

Gibberellins and ABA Interact during and Germination

• Many plants produce seeds that have to undergo a period of drying or a period of cold, wet conditions before they are able to germinate in response to warm, wet conditions.

  • In many plants, ABA is the signal that inhibits seed germination, and gibberellins are the signal that triggers embryonic development.
During seed germination, gibberellins activate production of α-amylase, a digestive enzyme that breaks the bonds between sugar units of starch. This releases sugars to the growing embryo.

ABA Closes Guard Cells in Stomata

- In most plants, stomata open in response to blue light, allowing gas exchange during photosynthesis. When stomata are open, water can be lost; if the roots cannot replace water lost at the leaves, then the stomata close.

- ABA from... is transported to leaves, resulting in the closure of stomata. Therefore, this signal overrides that from the blue-light receptors.

ABA and Senescence

- Senescence = regulated aging process.

- The gaseous hormone ethylene is strongly associated with three aspects of senescence in plants:
  - 1) __________
  - 2) flower fading
  - 3) abscission.

The abscission zone is a region of the leaf petiole that becomes more sensitive to ethylene as auxin levels drop. As a result, it degrades first and the leaf breaks off at this point.

Leaves Drop in Response to Signals from Auxin and Ethylene
Overview

Plant Growth Regulators

(1) A single hormone often affects many different target tissues. This means there can be an array of responses to the same intercellular signal.

(2) In most cases, several hormones affect the same response.

Hormones do not work independently—they ______ with each other.

Gravity: The Gravitropic Response

______ is the ability of plants to move in response to gravity. Roots grow down and shoots grow up or out.

Auxin as the Gravitropic Signal

- Root cap cells that sense changes in the direction of gravitational pull respond by changing the distribution of auxin in the root tip.

The Auxin Redistribution Hypothesis for Gravitropism

1. Normal distribution of auxin in vertical root prior to disturbance.
2. Root tip moved into horizontal position.
3. Gravity-sensing cells actively redistribute the auxin to the bottom side.
4. Asymmetric auxin distribution results in cell growth on lower side, leading to bending.

Auxin's Overall Role

- Auxin: controls growth via phototropism, gravitropism, and apical dominance.

- Auxin has other important effects as well:

- Fruit development is influenced by auxin produced by seeds within the fruit.

- Falling auxin concentrations are involved in ______ (the shedding of leaves and fruits) associated with ______ (aging).
How Do Plants Sense and Respond to Pathogens?

- If a pathogen invades a plant, the plant mounts a defense called the **hypersensitive response (HR)**. HR causes the rapid and localized death of cells surrounding the site of infection, killing the pathogen.
- Other Responses too...

**Herbivory**

= toxins
(Primary metabolites involved in homeostasis and typical cellular function)
- Tobacco makes nicotine
  - Harmful to many herbivores

**Secondary Metabolites**

- **Hormones/Pheromones**
  - Mimic juvenile hormone; stop molt to adult
  - Attract your herbivore’s insect prey!
  - Warn other plants to mobilize their defensive cascades
- **Poisons**
  - Disrupt nervous system of herbivore
    - nicotine
  - Disrupt digestive system of herbivore
    - proteinase inhibitors

**How Do Plants Sense and Respond to Herbivore Attack?**

- Many plant seeds and storage organs contain proteinase inhibitors, proteins that block the enzymes found in the mouths and stomachs of animals that digest proteins.
- When a herbivore ingests a large dose of a proteinase inhibitor, it gets sick. As a result, herbivores learn to detect and avoid plant tissues containing high concentrations of these proteins.

**Pheromones Released from Plant Wounds Recruit Help from Wasps**

- A parasitoid is an organism that is free living as an adult but parasitic as a larva. Because parasitoids (for example, a wasp egg laid in a caterpillar’s body) kill their host, parasitoid attacks limit the amount of damage that herbivores do to plants.
- **Pheromones** are chemical messengers synthesized by an individual and released into the environment that elicit a response from a different individual.
- Plants produce wasp attractant pheromones in response to attack by caterpillars.
### Secondary Metabolites

#### Table 1: Secondary Plant Metabolites Used in Defense

<table>
<thead>
<tr>
<th>Class</th>
<th>Type</th>
<th>Role</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen-containing</td>
<td>Alkaloids</td>
<td>Affect herbivore nervous system compounds</td>
<td>Tobacco nicotine</td>
</tr>
<tr>
<td></td>
<td>Glycosides</td>
<td>Release oxides or sulfur compounds</td>
<td>Dihydnaphthoquinone</td>
</tr>
<tr>
<td>Nonprotein amino acids</td>
<td></td>
<td>Disrupt herbivore protein structure</td>
<td>Capsazepine in jack bean</td>
</tr>
<tr>
<td>Phenols</td>
<td></td>
<td>Inhibit competing plants</td>
<td>Capsaicin in pepper</td>
</tr>
<tr>
<td>Terpenes</td>
<td>Monoterpenes</td>
<td>Insecticides</td>
<td>Quercetin in oak</td>
</tr>
<tr>
<td></td>
<td>Triterpenes</td>
<td>Phytoalexins</td>
<td>Quercetin in walnut</td>
</tr>
<tr>
<td></td>
<td>Steroids</td>
<td>Mimic insect hormones and plant defense</td>
<td>Quercetin in cotton</td>
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<td>Quercetin in cotton</td>
</tr>
<tr>
<td></td>
<td>Polysaccharides</td>
<td>Feeding deterrents</td>
<td>Lecithin in rubber tree</td>
</tr>
</tbody>
</table>

### Tannins

Grapes/wine

Oak leaves

### Milkweeds

Secrete a poisonous latex

Swallowtail butterflies incorporate milkweed toxins into their own tissues for defense (via bird learning)
Milkweeds

Secrete a poisonous latex

Some herbivores ‘learn’ to disable the defense (cut the latex supply lines, then eat the leaf!)

Another example of an

Cyanide (CN)

Cyanide is a very rapidly acting toxin (used by communes for suicide!).

In plants, CN is combined with sugar as a cyanogenic glycoside.

Precursors, stored in vacuoles, get together in cytosol if plant is damaged by wilting, crushing, or chewing.

More than 1000 plant species have cyanide in some form.

Aspirin!

- Salicylic Acid common in plants
  - Well-studied in Willows (Salix)
  - Used to combat many pathogens (e.g., viruses)

- Methyl salicylate, a related compound
  - aka ‘oil of wintergreen’
  - Volatilizes to signal other plants (~pheromone) to defend selves