Lectures 8 and 9

- Leaf/canopy microclimate is driven by **solar** and **terrestrial radiation inputs**
- Magnitude and wavelength range of radiation is dependent on temperature:
  - **Solar radiation**: **shortwave** (100-4,000 nm), divided into ultraviolet, photosynthetically active, and near infrared ranges; shortwave radiation incident on leaf/canopy/slope is highly dependent on orientation with respect to sun (point source); cloudiness also influences incident shortwave radiation
  - **Terrestrial radiation**: **longwave** (4,000-100,000 nm), calculated from Stefan-Boltzmann law; longwave radiation incident on leaf/canopy/slope has little dependence on orientation (terrestrial objects are not point sources)
- **Microclimate profiles** of radiation, air temperature, soil temperature, humidity, wind speed, and CO_2; Influence leaf/canopy energy balance and plant acclimation and adaptation

Lecture 10

- Energy balance: **energy in** = **energy out**, or absorbed energy = dissipated energy
- Leaf/canopy **temperature** is dependent on leaf/canopy energy balance
- Absorbed energy (**energy in**) is dependent on intensity of incident shortwave (solar) and incident longwave (terrestrial) radiation, and on leaf/canopy **absorptance**, **reflectance**, and **transmittance** (fractions of absorbed, reflected, and transmitted radiation must sum to one)
- Absorbed energy is dissipated (**energy out**) by:
  - **Re-radiation**: longwave radiation emission, dependent on temperature (Stefan-Boltzmann law)
  - **Sensible heat flux**: energy (heat) transferred to air by conduction/convection from leaves, dependent on temperature difference and boundary layer heat conductance (dependent on wind speed and leaf size) - Ohm's Law analogy
  - **Latent heat flux**: energy (heat) transferred to air by transpiration from leaves, dependent on evaporative gradient (dependent on air temperature and humidity, and leaf temperature), stomatal conductance, and boundary layer conductance - Ohm's Law analogy
  - **Soil heat flux** (if entire ecosystem and not just leaves are considered): energy transferred to lower soil layers by conduction, depends on temperature difference between surface and lower layers
- Leaf coupling factors (variables that plants can influence) partly control energy balance:
  - **Leaf orientation**: horizontal versus vertical leaves; diaheliotropic versus paraheliotropic leaves
  - **Leaf absorptance**: high versus low absorptance
  - **Leaf size**: large versus small leaves
  - **Leaf shape**: leaf serrations, leaf lobing, leaf tearing versus smooth/rounded edges
  - **Leaf stomatal conductance**: open versus closed stomata

Lecture 11

- Water use in plants:
  Less than 1 % used in **photosynthetic reactions** (light and dark reactions)
  Less than 5 % used for **cell growth** (filling of new cells)
  Greater than 95 % used for **CO_2 uptake** (lost as transpiration when stomata are opened)
- Due to huge differences in the **evaporative gradient** (large H_2O vapor gradient; **intercellular air spaces to atmosphere**) and **CO_2 gradient** (small CO_2 gradient; **chloroplast to atmosphere**), tens to hundreds of H_2O molecules are required for synthesis of a single sugar molecule; strong relationship between water use and photosynthesis/productivity: **water use efficiency = C fixed / H_2O lost**
- Water uptake and movement in plants (passive process, unlike nutrient uptake):
  Driven by water potential gradient: water flows from high potential to low potential
  Water potential of atmosphere < leaf < xylem < root < soil
- **Plant response** to reduced hydraulic conductivity of xylem conduits (embolize conduits), reduced soil water availability (dry soil to lower water potential), and increased evaporative gradient between leaves and atmosphere:
  Leaf pressure drops
  Stomata close: photosynthesis declines as a result
  Water flow drops
  Leaf pressure rises to new set point
- **Stomatal regulation** of water potential gradient between roots and leaves limits water loss, and as a Result photosynthesis; this is necessary to prevent wilting and cellular damage in leaves and cavitation of xylem conduits

Lecture 12

- Essential plant nutrients: macronutrients and micronutrients; plant growth is usually limited by **nitrogen** or **phosphorus**
- **Sources of nutrients**: weathering of parent material, atmospheric deposition, nutrient recycling within ecosystems, biological nitrogen fixation, anthropogenic addition (fertilizer)
- Nutrient transport to plant root surfaces:
  Diffusion in water: ions diffuse in water from high nutrient concentration (soil) to low nutrient concentration (rhizosphere/root surface)
  Mass flow in water: movement of water (plant uptake, infiltration) moves nutrients towards root surface
  Interception by roots: growth of roots into new areas of soil, enhances diffusion
  Symbioses: mycorrhizal associations with fungi and associations with N-fixing bacteria; requires resources from plants
- Nutrient transport into roots: nutrient concentration is **high in roots** and **low at root surface**, does not favor diffusion into roots - **energy is required** (active transport/transport respiration)
- **Nutrient uptake rate** in roots depends on root length (surface area), diffusion of nutrients to root surface, energy allocated to nutrient uptake (transport respiration), and demand by plant
- **Diffusion to root surfaces is typically the limiting process**; potential solutions:
  Increase fraction of roots
  Increase number of root hairs
  Symbiotic associations
- Photosynthesis in most plants increases when nutrients are added, **nutrient availability in soil** likely controls uptake and growth

Lectures 13 and 14

- Photosynthesis dependent on simultaneous absorption of photosynthetically active photons and diffusion of CO_2 from air to chloroplast:
  - **Photon absorption** dependent on incident solar radiation and leaf chlorophyll content
  - **CO_2 diffusion** dependent on limitations by boundary layer, stomata, and internal transport
- **Light reactions** and **machinery** (light harvesting complex, photosystems I and II): energy from absorbed photons used to split water and produce ATP and NADPH via electron transport chain
- **Dark reactions**: Rubisco combines CO_2 and RuBP, ATP and NADPH are used to synthesize simple sugars and regenerate RUBP; Rubisco can operate as a carboxylase (**carbon fixation**) and oxygenase (**photorespiration**)
- Like leaf transpiration rate, **leaf photosynthesis rate** can be described with an Ohm's Law analogy equation: ratio of leaf photosynthesis rate to transpiration rate = **water use efficiency**
- **A_n-C_i curve**: leaf net photosynthesis response to intercellular CO_2 (leaf's capacity to photosynthesize)
  - Different limitations depending on conditions: **CO_2 (diffusion)** versus **RuBP (electron transport)**
- **A_n-PPFD curve**: light response curve
  - Different limitations depending on conditions: **PPFD (light reactions)** versus **carboxylation (dark reactions)**
- Photosynthetic rate is determined by **supply of and demand for CO_2**; plants tend to operate in the range where **supply of CO_2 and RuBP co-limit A_n** (optimization of light and dark reactions)
- **Sun leaves** versus **shade leaves**: structural, biochemical, and gas exchange acclimation in response to environment

Lectures 15 and 16

- Primary production:
  - GPP: **gross primary production** (ecosystem-scale net photosnythesis); GPP = NPP + R_p
  - NPP: **net primary production** (plant biomass increase); NPP = GPP – R_p; highly dependent on climatic conditions, particularly precipitation and temperature
  - R_p: **plant respiration** (respiration from stems, roots, reproductive structures, and leaves at night)
- Top-down models for estimating primary production:
  - Based on linear relationship between absorbed photosynthetically active radiation and primary production canopy light use efficiency, **canopy light use efficiency** is the slope: NPP = $\alpha_c PPFD_c LUE_c$
- Bottom-up models for estimating primary production:
  - Attempt to combine mathematical descriptions of processes (radiation absorption, photosynthetic response, respiratory energy use, water uptake and transport, leaf energy balance, nutrient uptake and transport) influencing production
  - Split plant canopy into **multiple layers**, calculate production for each layer, sum results based on **leaf area index** for each layer
  - (Simplest bottom-up models rely on **light response curves** and **leaf area index** for **leaf layers**, where a **light transmission** model for the plant canopy is used to determine absorbed radiation at each layer)
- **Canopy structure** (**leaf area** and **leaf angle** in each layer of leaves) has a major influence on radiation transmission to lower leaf layers model for estimating primary production:
  - Deciduous tree canopies tend to have **more leaf area near the top** of the canopy and **more horizontal leaf angles**
  - Grass canopies tend to have **more leaf area in the near the bottom** of the canopy and **more vertical leaf angles**
  - Canopy photosynthesis response to photosynthetically active radiation (light response curve at the canopy scale) is nearly linear due to canopy structure (**multiple leaf layers all contribute**)

Lecture 17

- Allocation of **photosynthetic products** (GPP) to NPP and R_p: NPP / GPP ≈ 0.5 and R_p / GPP ≈ 0.5
- Allocation of **NPP**:
  Most to **new plant biomass** (leaves, branches/stems, roots, reproductive parts)
  Some to microbial symbionts
  Highly variable, dependent on conditions driving plant demand (what is needed)
  Multiple tradeoffs because plants function as **integrated systems**: finite amount of resource is available and allocation to one tissue means resource is not available for another
- Allocation of $\mathbf{R_p}$:
  Growth respiration: energy used for new growth, depends on construction costs of material (leaves, branches/stems, roots, reproductive parts) and plant demand for new material
  Maintenance respiration: energy used to **maintain living tissues**; proteins/enzymes have high maintenance costs
  Transport respiration: energy used to **move nutrients/photosynthetic products** from one place to another; large cost associated with nutrient uptake in roots (active transport to move ions against concentration gradient)
- **Phytochromes** (pigment in apical meristems) regulate multiple plant functions depending on **configuration of pigment**:
  Timing of flowering, germination of seeds, elongation of seedlings
  Distance between leaves; **number, size, and shape of leaves**; **allocation of resources to leaves** (leaf nitrogen example)
- Ratio of **red to far red light** determines phytochrome configuration:
  Above canopy: more red light relative to far red light
  Within canopy: more far red light relative to red light (red is absorbed by chlorophyll in leaves, far red is largely transmitted by leaves)
- Allocation to **defenses**: tradeoff between traits that maximize photosynthesis and growth, and traits that maximize leaf longevity (investment in photosynthetic machinery versus investment in maintenance and defenses)

Lecture 18

- Percent of annual plants increases as environmental predictability decreases: seeds can be dormant for extended periods of time
- Improved reproductive success requires increased allocation of resources to reproduction: tradeoffs
- Different seed strategies:
  Large seeds: shorter dispersal, fewer produced, more competitive
  Small seeds: shorter dispersal, fewer produced, more competitive
- Evidence for **competition**: through observation and experimentation
- Competition isn't always fair: **symmetric** competition and **asymetric** competition
- Resources plants are competing for:
  $\mathbf{CO_2}$: likely little competition, air is well mixed
  Light: must increase allocation to stems and leaves (occurs when resources are abundant)
  Water: must increase allocation to leaves
  Nutrients: must increase allocation to roots
  Space: must increase allocation to roots, stems, leaves (fast growing species)
- Consequences of competition:
  Can narrow **species ranges**
  Across species, exotic **invasive species** can influence **native species** (usually negatively), but competition promotes diversification of resource use
  Within species, competition promotes better **adaptation**