

Plant Ecology, Examination 2
November 3, 2011

Name _____
Student ID _____

Answer all questions fully and directly, but please restrict your responses to the spaces provided. Point totals for each question are given in parentheses.

(6) 1a. For each leaf characteristic listed in the table below, indicate whether the characteristic is low, high, or similar when comparing sun and shade leaves.

	Sun Leaves	Shade Leaves
Structural Characteristics:		
Mesophyll thickness	High	Low
Chloroplasts per leaf area	High	Low
Biochemical Characteristics:		
Light harvesting complex per leaf area	Low	High
Rubisco per leaf area	High	Low
Gas Exchange Characteristics:		
Photosynthetic capacity per leaf area	High	Low
Quantum yield	Similar	Similar

Explain your reasoning for each characteristic with respect to the answers provided in the table for sun and shade leaves.

(2) 1b. Mesophyll thickness

Sun leaves are acclimated to high light environments and shade leaves are acclimated to low light environments. High light means potential for photosynthesis is high, but high photosynthesis requires multiple mesophyll layers. In low light, potential for photosynthesis is lower, thus fewer mesophyll cells.

(2) 1c. Chloroplasts per leaf area

Similar to answer for 1b. High light means potential for photosynthesis is high, but this requires a high number of chloroplasts per leaf area for carbon fixation. In low light, potential for photosynthesis is lower, thus fewer chloroplasts per area are required.

(2) 1d. Light harvesting complex per leaf area

High light environment for sun leaves makes it easier for them to capture radiation, thus fewer light harvesting complexes per area are required. The opposite is true for shade leaves. They have more light harvesting complexes per area to try to capture all available light in a low light environment.

(2) 1e. Rubisco per leaf area

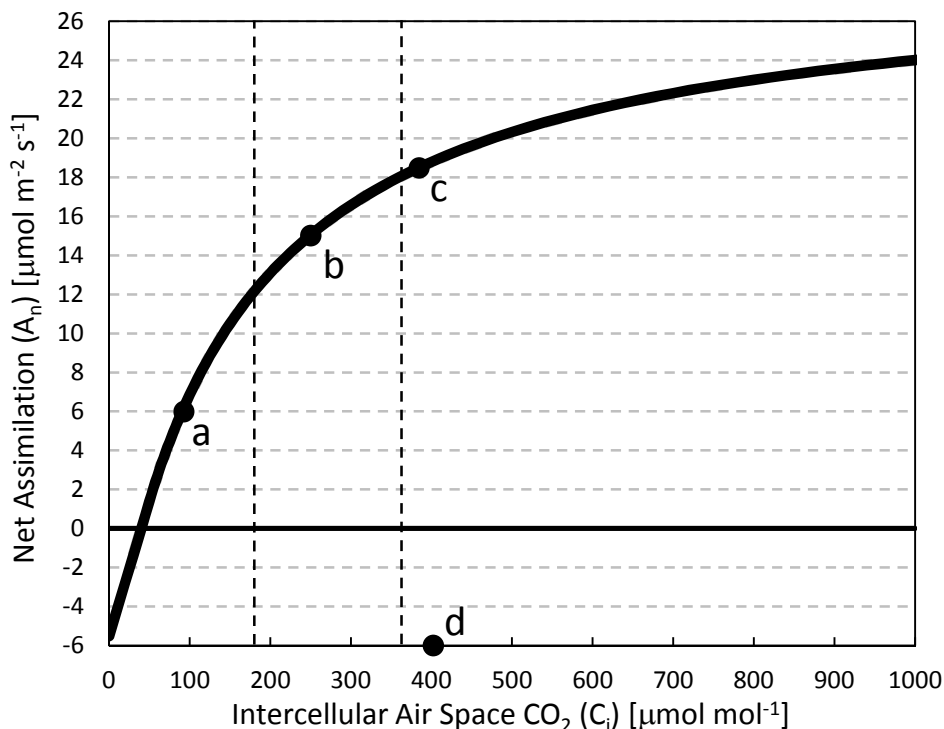
Rubisco catalyzes the first step in the dark reactions, attaching CO₂ to RuBP. In high light environments, high levels of Rubisco are required to keep up with the light reactions (light capture and synthesis of ATP and NADPH). The opposite is true in low light environments, less Rubisco is required.

(2) 1f. Photosynthetic capacity per leaf area

Photosynthetic capacity is high in sun leaves because potential for photosynthesis is high, and resources are allocated to produce a high carboxylation capacity (high chloroplast and high Rubisco per area). In shade leaves potential for photosynthesis is low, thus chloroplast and Rubisco per leaf area are low.

(2) 1g. Quantum yield

Similar quantum yields for sun and shade leaves represents an optimization of structural, biochemical, and gas exchange characteristics by plants, in an attempt to maximize photosynthesis given the available resources.



Assume atmospheric CO₂ is at point d.

(3) 3a. The leaf is operating at point a. Describe the limitation to photosynthesis.

There is a large difference between C_a and C_i, thus diffusion of CO₂ from atmosphere to chloroplast is limiting.

(3) 3b. The leaf is operating at point c. Describe the limitation to photosynthesis.

There is a small difference between C_a and C_i, but A_n does not continue to linearly increase, thus electron transport from the light reactions and regeneration of RuBP is limiting.

(4) 3c. At what C_i value will leaf respiration balance photosynthesis? What are two sources of leaf respiration during the day?

C_i ≈ 40 μmol mol⁻¹. Photorespiration and mitochondrial respiration (growth and maintenance).

(6) 3d. If the leaf is operating at point b, what is the total conductance to CO₂?

Remember: $A_n = g_{CO_2}(C_a - C_i)$. Show the calculation. List the three conductors that combine to yield g_{CO_2} .

$$g_{CO_2} = A_n / (C_a - C_i), C_a = 400 \mu\text{mol mol}^{-1}, C_i \approx 250 \mu\text{mol mol}^{-1}, A_n \approx 15 \mu\text{mol m}^{-2} \text{ s}^{-1}$$

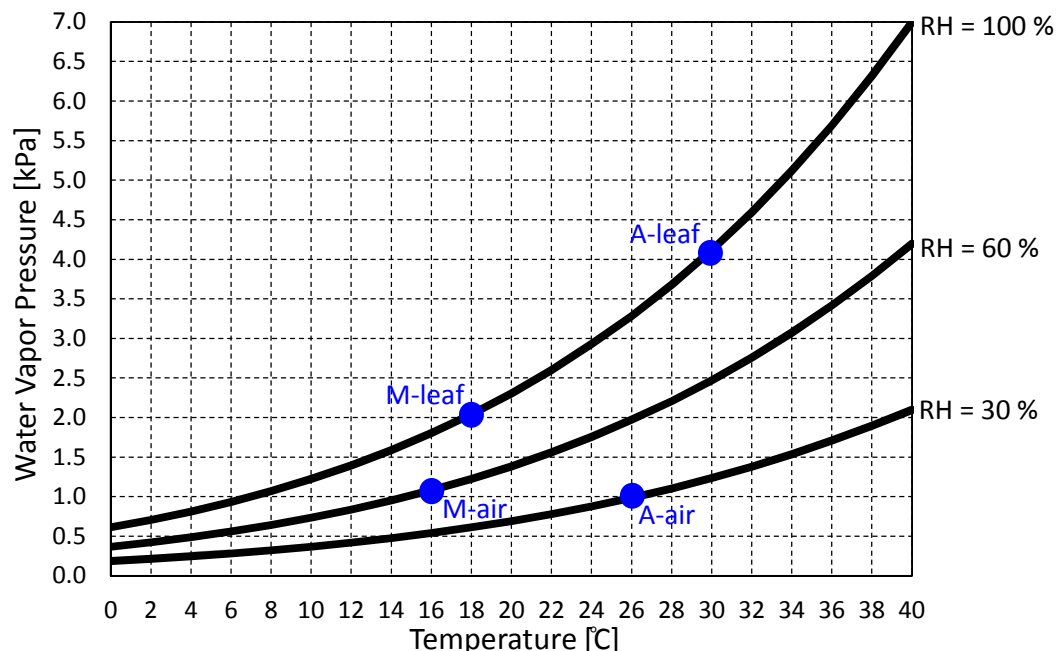
$$g_{CO_2} = 15 \mu\text{mol m}^{-2} \text{ s}^{-1} / (400 \mu\text{mol mol}^{-1} - 250 \mu\text{mol mol}^{-1})$$

$$g_{CO_2} = 15 \mu\text{mol m}^{-2} \text{ s}^{-1} / 150 \mu\text{mol mol}^{-1} = \mathbf{0.1 \text{ mol m}^{-2} \text{ s}^{-1}}$$

Boundary layer conductance, stomatal conductance, internal (mesophyll) conductance.

(6) 3e. If the plant is experiencing water stress, is it more likely to operate at point a or point c? Justify your answer.

Point a. At point a CO₂ diffusion from the atmosphere to chloroplasts is the limitation to photosynthesis. When plants are water stressed, they usually close stomata in order to conserve water. Reduced stomatal conductance represents a diffusional limitation to photosynthesis.



(2) 4a. In the morning, the following conditions were measured: air temperature = 16°C, air relative humidity = 60 %, leaf temperature = 18°C. What is the evaporative gradient from leaf to air?

Plot the air and leaf vapor pressures on the graph with labels of M-air and M-leaf.

Evaporative gradient = vapor pressure difference between leaf and air ($e_{\text{leaf}} - e_{\text{air}}$).

$$e_{\text{leaf}} \approx 2.0 \text{ kPa} \quad e_{\text{air}} \approx 1.0 \text{ kPa} \quad e_{\text{leaf}} - e_{\text{air}} = 2.0 \text{ kPa} - 1.0 \text{ kPa} = 1.0 \text{ kPa}$$

(2) 4b. In the afternoon, relative humidity of the air decreased from 60 % to 30 %, air temperature increased to 26°C, and leaf temperature increased to 30°C. What is the evaporative gradient from leaf to air? Plot the air and leaf vapor pressures on the graph with labels of A-air and A-leaf.

$$e_{\text{leaf}} \approx 4.0 \text{ kPa} \quad e_{\text{air}} \approx 1.0 \text{ kPa} \quad e_{\text{leaf}} - e_{\text{air}} = 4.0 \text{ kPa} - 1.0 \text{ kPa} = 3.0 \text{ kPa}$$

(6) 4c. Measurements of leaf transpiration rates showed similar values in the morning and afternoon. What leaf response may have caused this? Justify your answer.

There must have been a change in a leaf coupling factor, for example, stomatal closure or a change in leaf orientation. Stomatal closure would directly reduce stomatal conductance, and counter-balance the increase in the evaporative gradient. A change in leaf orientation could reduce the incident shortwave radiation, causing the leaf to operate a lower photosynthesis rate and allowing partial stomatal closure, which would counter-balance the increase in the evaporative gradient.

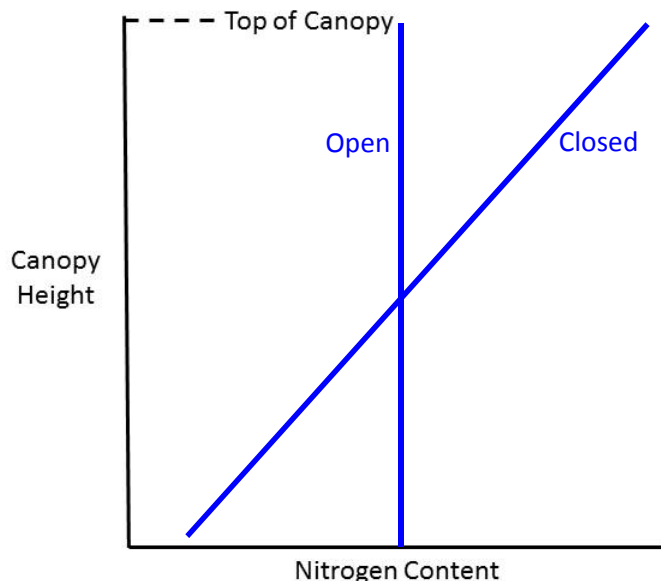
(6) 4d. Assuming a decreasing net photosynthesis rate from morning to afternoon, how did water use efficiency change from morning to afternoon? Justify your answer.

$WUE = C_{\text{fixed}} / H_2O \text{ lost} = \text{net photosynthesis rate} / \text{transpiration rate}$.

Transpiration rates were similar, but net photosynthesis rate declined from morning to afternoon. If the numerator decreases, but the denominator remains constant, less C is fixed per H_2O lost, WUE declines.

(6) 4e. Certain species have the ability to decrease effective leaf length under conditions of water stress. In terms of energy balance, why is it advantageous for a plant to be able to acclimate in this manner?

When plants are water stressed, stomata close to conserve water. As a result, evaporative cooling of the leaf decreases because transpiration (latent heat flux) is reduced. Decreasing the effective leaf length increases the boundary layer conductance, as smaller leaves have thinner boundary layers, making sensible heat transfer more efficient. An increase in sensible heat flux can counter-balance the reduced latent heat flux and keep leaves cooler than they would otherwise be.



(2) 5a. On the graph above, draw the expected relationship between leaf nitrogen content and canopy height for a typical closed canopy. Label the line 'closed'.

(2) 5b. On the graph above, draw the expected relationship for a canopy where the profile of photosynthetically active radiation (PAR) is uniform from top to bottom. Label the line 'open'.

(4) 5c. Explain why these relationships are observed for the open and closed canopies.

Nitrogen content of leaves is highly dependent on the average PAR absorbed by leaves because more photosynthetic enzymes, which contain lots of nitrogen, are required to fix more carbon in high PAR environments. PAR in closed canopies decreases from top to bottom of the canopy, thus the nitrogen profile decreases. The profile of PAR is uniform in the open canopy, thus the nitrogen profile is uniform.

(4) 5d. At what position within the closed canopy would maintenance respiration rate likely be highest? At what position within the open canopy would maintenance respiration rate likely be highest? Justify your answers for each canopy.

Maintenance respiration is likely highest at the top of the closed canopy because nitrogen content of leaves is highest at the top of the closed canopy, and maintenance respiration scales with nitrogen content (proteins contain a lot of nitrogen and require high maintenance). Maintenance respiration in the open canopy is likely relatively uniform with height because nitrogen content is uniform.

(6) 5e. Explain the differences in canopy structural traits that likely cause the differences in nitrogen profiles between the open and closed canopies.

Closed canopies tend to have relatively high leaf area and/or relatively horizontal leaf angles near the top of the canopy, and PAR is absorbed going from the top to the bottom of the canopy. Thus, less PAR is incident at each level, and less nitrogen is required. Open canopies tend to have relatively low leaf area and/or relatively vertical leaf angles near the top of the canopy. Thus PAR, and subsequently nitrogen content, is more uniform.

(2) 5f. Is the nitrogen profile of the closed canopy more likely representative of a forest or grassland? Is the open canopy nitrogen profile more likely representative of a forest or grassland?

Closed canopy is likely a forest.

Open canopy is likely a grassland.

Optional Bonus Questions

(2) 6a. What is a typical value for the ratio of red to far red radiation above a plant canopy? What is a typical value for the ratio of red to far red radiation below a plant canopy?

Above a plant canopy: red / far red > 1 .

Below a plant canopy: red / far red < 1 (potentially $\ll 1$ depending on number of leaf layers).

(2) 6b. Explain the plant mechanism that causes differences in red to far red radiation ratios above the canopy versus the bottom of the canopy?

Chlorophyll absorbs much of the red radiation because it is within the photosynthetically active range.

Chlorophyll does not absorb much of the far red radiation because it is outside the photosynthetically active range. As a result, there is little transmission of red radiation to lower canopy layers, but high transmission of far red radiation. Above the canopy, chlorophyll in leaves has yet to absorb radiation.

(2) 6c. List two plant characteristics/functions that are regulated by phytochrome.

Any two of the following:

Timing of flowering

Germination of seeds

Elongation of seedlings

Distance between leaves

Leaf number, size, and shape

Allocation of resources to leaves