

Please acknowledge that you will not cheat in any way on this exam and, furthermore, that you will not allow others to look at your exam during the exam period. If you agree, please sign your name on the back of this page. Exams that have not been signed will not be graded. Please restrict your response to the space available; do not extend your answers to the back of the paper. Answer directly and fully - don't beat around the bush. The point values for each question are given in parentheses. Any notes you added to printouts of Wanda Weatherley's notebook are allowed in answering the exam.

page 425 Some of the most unusual growth responses I have observed recently are the comparative growth responses of *Helioattractus vulgaris* and *Nocturnus platyphylla*, two herbaceous species common to the understory riparian tree communities in our nearby mountains. Both species have an opposite leaf arrangement. *Helioattractus vulgaris* is a competitive species, often overtopping and shading its neighbors. *Nocturnus platyphylla* is a long-lived herbaceous species (>10 years) that grows well in the understory of many forest canopies. Below are the growth observations I made for plants growing at different locations. I then measured the nitrogen content of the uppermost leaves of *Helioattractus vulgaris* and *Nocturnus platyphylla* leaves.

Height above ground (cm)	Midday light level (% of sunlight at the top of the tree canopy)	Ratio of red to far red light at this height in the canopy	Average internodal distance of 3 leaves of <i>Helioattractus vulgaris</i> at this height (cm)	Average internodal distance of 3 leaves of <i>Nocturnus platyphylla</i> at this height (cm)	Percent leaf nitrogen content of 3 leaves of <i>Helioattractus vulgaris</i> at this height	Percent leaf nitrogen content of 3 leaves of <i>Nocturnus platyphylla</i> at this height
22	4	0.7	10	3	1.0	1.2
142	24	1.9	4	4	2.5	1.2
78	16	1.0	8	4	1.5	1.1
250	44	3.2	2	3	3.1	1.0
187	30	2.3	4	4	2.7	1.1

Please note that the data above represent 10 different plants (5 of each species).

1 (12) Please provide a mechanistic explanation as to why there are variations in the internodal distances of *Helioattractus vulgaris* plants. Your explanation **must** include the observed linkages between environment, photoreceptors, and growth.

Phytochrome [biochemistry] in the apical meristems of *Helioattractus vulgaris* is sensing plant position in the canopy [shadiness, environment] and regulating internodal distances [growth]. If you look closely at the dataset, you will see that there is a linear relationship between R:FR ratios and internodal distance. Furthermore R:FR ratios are linearly related to midday light levels at that position within the canopy.

2 (10) Provide an explanation for anticipating a positive relationship between photosynthetic capacity and height in leaves of *Helioattractus vulgaris*.

Photosynthetic capacity is linearly related to leaf nitrogen content. If we look at the leaves of *Helioattractus vulgaris*, we see that leaf nitrogen content is positively and linearly related to light levels in the canopy. As leaf proteins turnover at a high rate and are energetic expensive, leaves produce different greater or lesser amounts of protein in order to produce a photosynthetic apparatus best able to fix the highest net gain of carbon dioxide in particular environments.

3 (7) What is the basis for the observed variations in the ratios of red to far-red light as a function of canopy height?

The ratios of red to far-red light vary through the canopy because chlorophyll in leaves is absorbing the red wavelengths and not the far-red wavelengths.

Page 427. Last week I got into a terrible argument with a colleague about what metabolic and biochemical components of photosynthesis are sensitive to temperature. My colleague stated that if you exposed a sun-lit leaf from a plant grown at 25 °C to high leaf temperatures (say 48 °C) for a brief period of time (say 5 to 10 minutes) and then returned the leaf temperature to 25 °C that the rate of photosynthesis measured at 25 °C would decline relative to a control (a plant that had been exposed only to 25 °C). On that we both agreed. Where we differed was on the mechanistic basis for the decline in photosynthetic rate following exposure to high temperature. He argued that the decline in photosynthesis was caused by the temperature sensitivity of photosystem I reactions. I argued that the decline in photosynthesis following leaf exposure to the high temperature was caused by the temperature sensitivity of photosystem II reactions. Then, another colleague came by and made the claim that the decline in photosynthesis following leaf exposure to high temperature was caused by the temperature sensitivity of the Hill reaction. Now I am confused.

4 (3) If we measure leaf-level photosynthesis as the net carbon dioxide uptake rate by the leaf, should that measurement be sensitive to photosystem I or photosystem II activities in response to exposure to high leaf temperatures? Circle one: **YES**

5 (9) If we measure leaf-level photosynthesis as the net carbon dioxide uptake rate by the leaf, WHY or WHY NOT should that measure be sensitive to photosystem I or photosystem II activities in response to exposure to high leaf temperatures?

The overall rate of carbon dioxide uptake is sensitive to temperature. The photons necessary to produce ATP and reduce NADPH are products of the photosystem I and II reactions. If photosystem I and/or II are temperature sensitive, then the overall rates of carbon dioxide uptake in photosynthesis will be reduced because the energy to drive the carbon reduction cycle is lessened.

6 (8) Two of the three people have the correct understanding of the mechanistic basis for the decline in photosynthesis. What experiments, or set of measurements, would you conduct in order to find out which of the proposed explanations was really responsible for the decline in photosynthesis after leaf exposure to high temperatures. Be concise in your explanation.

The linear sequence of photosystem reactions is (a) the splitting of water and produce diatomic oxygen, followed by (b) ATP production, and then (c) reduction to produce NADPH. If we were to not detect production of ATP and diatomic oxygen, then we would suspect that photosystem II activities has ceased. By placing a source of electrons into the biochemical pathway at specific points as a source for photosystem I reactions, we could determine if this component was failing at high temperatures.

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In southern Utah, I noticed that age distributions of a hemi-parasitic mistletoe were not normally distributed when the abundances of these parasites were counted on different juniper trees (host species). Mistletoe mortality is known to be associated with extreme climate events, such as the 2-4 year long drought such as we are experiencing now in Utah. On the other hand, success in mistletoe establishment is thought to be associated with springtime soil moisture conditions.

Age category of mistletoes on the host tree	Number of mistletoes on tree #1	Number of mistletoes on tree #2	Number of mistletoes on tree #3	Number of mistletoes on tree #4
1 year old	15	14	7	19
2 years old	27	33	23	23
3 years old	33	39	29	33
4 years old	20	30	32	28
5 years old	32	27	33	31
6 years old	29	32	28	28
7 years old	26	30	26	29
8 years old	1	2	1	0
9 years old	1	0	0	1
10 years old	1	0	1	0

At the same time, I evaluated seed production in these same mistletoes. In their reproductive cycle, mistletoes flower in the spring, seed development takes place in the summer, and seeds are dispersed in the fall. One unusual phenomenon I observed was that the average seed biomass of mistletoe seeds was not constant across different aged mistletoes. After measuring seed mass, I brought the seeds from these mistletoes back into the laboratory measured the chemical composition on a subset of the seeds and conducted germination studies on another random subset of the seeds. Germination was not delayed in this species and seeds germinated within 4 days or did not germinate at all. All of those data are summarized below.

Age of mistletoe	Mistletoe seed mass (mg)	Germination rate (%)	Seed lipid content (%)	Seed starch content (%)
1 year old	12	20	7	37
2 years old	17	42	8	44
3 years old	20	54	7	52
4 years old	22	82	7	71
5 years old	23	87	8	80
6 years old	26	92	6	82
7 years old	26	89	7	81
8 years old	28	96	8	84
9 years old	31	98	6	82
10 years old	33	98	7	83

Mistletoe seeds germinate on the surface of host stems. Seeds that germinate from older mistletoe plants are more likely to get established than seeds from younger plants. The secret to success in

mistletoe establishment is rapid production of a root that is long enough to find a penetration point where the mistletoe can tap into its host's xylem tissues before the seedling tissues desiccate.

7 (5) What dominant carbon-based reserve is available for growth of mistletoe seedlings? starch

8 (9) Is germination rate positively or negatively related to total carbon reserves? What is the basis of this conclusion?

The germination rate is positively correlated with seed mass. The basis of this conclusion is the observed positive correlation in the data presented.

9 (13) What is the significance of increasing starch content in seeds from maternal plants of different ages?

The significance of increasing starch content in seeds from maternal plants of different ages is that it appears that mothers are better able to provision their progeny with more resources with parental age, which has the effect of increasing the probability of germination and establishment (through enhanced radical development).

BONUS QUESTION (10). What do the mistletoe data above tell you about

(a) the time of the last mortality event before the current drought period?

The last significant mortality event occurred 8 years ago, because there is an abrupt loss of mistletoes 8 years and older from the population.

(b) the ESTABLISHMENT RATE of new mistletoes over the last seven years?

The establishment rate of new mistletoes appears to be constant through time.

While walking between campus and home each day, I pass along a natural grassland next to an iron smelter. Two of the most unlikely "sister" species occur in this grassland: *Cannonus erectus* and *Cannonus platyphylla*. Both species have very attractive flowers, but neither species ever seems to attract any attention by pollinators (typical for the genus), and so I am guessing that each is self compatible. Once a month I spend a day in this grassland measuring a number of key plant features: leaf water potential (units are MPa), leaf angle (units are degrees above the horizontal), and maximum leaf width (units are mm). All of the values within a column are statistically different from each other if they differ by more than 0.15 units.

	C. erectus	C. platyphylla	C. erectus	C. platyphylla	C. erectus	C. platyphylla
	Water potential	Water potential	Leaf angle	Leaf angle	Leaf width	Leaf width
	(MPa)	(MPa)	(degrees)	(degrees)	(mm)	(mm)
Feb 1	-1	-1.2	5	5	16	32
Apr 1	-1.5	-2.1	30	6	18	21
Jun 1	-2.5	-3.3	55	6	15	15
Aug 1	-3	-3.7	70	5	16	12
Sep 1	-3.5	-4.2	84	10	15	11

10 (10) Which of the two species shows a significant decrease in incident solar radiation as increasing water stress develops through the growing season? What is the evidence in support of this?

Cannonus erectus

The evidence to support this is the positive correlation between leaf angle and water potential in *Cannonus erectus* observed in the table above and the lack of a significant leaf angle changes in *Cannonus platyphylla*.

11 (10) In *Cannonus platyphylla*, leaf width is significantly correlated with water potential. Please interpret this correlation with respect to the anticipated relationship between transpiration and water potential as plants become more stressed during the growing season.

Both convective and latent heat cooling will reduce leaf temperatures in plants. Under increased water stress, stomata tend to close in leaves, reducing transpiration and reducing latent heat loss. By decreasing leaf width under water stress, *Cannonus platyphylla* leaves increase the amount of convective cooling and offset some of the loss of cooling capacity associated with diminished transpiration rates.

12 (10) If you now learned that *Cannonus erectus* OR *Cannonus platyphylla* actually grew only in the shade of dense oak trees in this natural grassland, which of the two species is more likely to occur in shade environments given the information above? Provide an insightful explanation for your decision.

Cannonus platyphylla

This is because there would be no advantage to increasing leaf angle to avoid high solar radiation loads if a plant were growing in the shade.