

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 558. Every other year at the winter and summer solstices, my nephew Waylon Weatherley and I leave [Wanship](#), Utah and travel to Tucson, Arizona; we camp at the base of [Tumamoc Hill](#), which has a rather steep, north-facing slope (data are slope azimuth of -175 degrees and slope angle of 55 degrees). The first thing that you notice is the contrast in solar insolation, but then we see the big vegetation differences. On the hill slope above where we camp, none of the annual herbaceous species present in winter have [Kranz anatomy](#), but in the summer 92% of the herbaceous species have Kranz leaf anatomy. None of the shrub or tree species has Kranz anatomy. I am sure that another observation is related. None of the herbaceous species in winter expressed leaf heliotropic behavior, whereas it was common across many taxa in the summer herbaceous flora. This behavior difference seemed odd until I remembered the slope-azimuth data.

1 (10). Please provide a quantitative comparison of the direct solar radiation incident on this slope at the two solstices. Your statement **must** be a comparison.

(10) The solar radiation incident on the slope is greater on Jun 21 than on Dec 21, both in terms of maximum intensities (834 vs 141 $\mu\text{mol}/\text{m}^2/\text{s}$) and daily integrated totals (24.7 versus 3.1 $\text{mol}/\text{m}^2/\text{day}$).

2 (10). What is the relationship between Kranz anatomy and photosynthetic pathway?

(10) Kranz anatomy is found in C_4 photosynthesis plants and not in C_3 photosynthesis plants.

3 (10). Contrast why it is likely that heliotropic behavior is common in the herbaceous species in one season and not the other.

(10) Heliotropic behavior is leaf movements in response to changes in the incident direct solar radiation intensities. It is more common in summer (when there is abundant direct beam) than in winter (when there is essentially only a limited amount of direct solar radiation).

page 670. My grand nephew Wally Weatherley just took Professor Ehleringer's class on Plant Ecology in a Changing World. He particularly enjoyed the student-led debate on fire ecology. Wally told me that this debate convinced him of the importance of educating the public about the natural "healthy" role of fires in sustaining many forest ecosystems. He is worried about discussing this issue with his father, who he thinks is convinced that fighting all fires in forest, shrubland, and grassland ecosystems is the best national policy. In fact, just recently Wally overheard his father talk to a firefighter. "Did you know that trees with serotinous cones die during an intense fire? And the 1988 Yellowstone fires were the worst possible event that could have happened to a redwood tree. Not a single dead tree survived", chuckled his father. The firefighter nodded in complete agreement. Wally has asked me to broker a peace between he and his father, in the event that an argument broke out. "Tell him he is wrong", I demanded. But first, I told Wally that I needed to know the arguments for and against a "Let-it-burn" forest-fire policy.

4 (10). Please provide three (6 total) distinct arguments "for" and "against" fighting forest fires in the western United States.

For (2 points for the first two answer; 1 point for the third answer; -1 for incorrect answers)

- **protect property structures**
- **protect valuable timber**
- **maintain scenic vistas (I like green trees)**
- **it helps support the economy (hires firefighters)**

Against (2 points for the first two answer; 1 point for the third answer; -1 for incorrect answers)

- **fires are a natural part of the ecological landscape**
- **allowing small fires allows dominant trees to persist by eliminating other smaller plants**
- **many seeds will not germinate unless they experience high temperatures (aka fires)**

5 (5). Although it is clear that the trees in Yellowstone that burned during the 1988 fire were largely lodgepole pine and not redwood trees, do lodgepole pines have serotinous cones? YES or NO.

(5) Yes.

Eucalyptus globulus is a tree native to the arid regions of Australia. It has become an invasive tree throughout California, Chile, Portugal, France, and Italy because it survives so well in water limited conditions, such as the summer droughts in a Mediterranean climate. Last year I spent 3 months touring Australia and measured spectral characteristics of its evergreen leaves that are often covered with waxes. Following rain storms in late autumn, the waxes fall off the leaf, washed away by the physical pressure of the striking raindrops. Three sets of observations below highlight how well-adapted this species is to the drier parts of Australia.

| Leaf spectral observations at different wavelengths (nm) | Leaf absorptance with wax (%) | Leaf absorptance without wax (%) | | Tree # | Mean leaf angle observations (degrees from horizontal) |
|--|-------------------------------|----------------------------------|--|--------|--|
| 375 | 50 | 50 | | | |
| 400 | 78 | 96 | | 1 | 87 |
| 425 | 78 | 96 | | 2 | 87 |
| 450 | 70 | 90 | | 3 | 89 |
| 475 | 70 | 90 | | 4 | 88 |
| 500 | 70 | 88 | | 5 | 86 |
| 525 | 60 | 88 | | 6 | 88 |
| 550 | 50 | 86 | | 7 | 85 |
| 575 | 54 | 88 | | 8 | 89 |
| 600 | 61 | 90 | | 9 | 89 |
| 625 | 67 | 92 | | 10 | 86 |
| 650 | 68 | 95 | | 11 | 87 |
| 700 | 69 | 96 | | 12 | 88 |
| 725 | 21 | 25 | | | |
| 750 | 4 | 3 | | | |
| 775 | 1 | 1 | | | |
| 800 | 1 | 1 | | | |

6 (10). Please circle all correct answers.

- A. Leaf absorptance maxima at 550 nm reflects the absorption spectrum of chlorophyll a.
- B. The absorptance spectra above are consistent with *Eucalyptus* waxes being blue in color.
- C. The steep leaf angles in *Eucalyptus* leaves will maximize solar radiation absorption at noon.
- D. The combination of low leaf absorptance and steep leaf angles maximizes solar radiation in *Eucalyptus* leaves.

(10) NONE of the above is correct.

9 (15). *Eucalyptus globulus* is now a worldwide invasive tree species in Mediterranean-climate regions around the world today. Contrast the solar radiation levels incident on *Eucalyptus globulus* leaves during the wet growing season versus the dry drought season.

(5) The wet season in a Mediterranean climate is the winter months. The dry season in a Mediterranean climate is the summer months. [When are wet/dry seasons?]

(10) Because the sun is at a higher elevation during the summer than in the winter, incident solar radiation levels on the vertical leaves of *Eucalyptus* will be greater in winter (wet season) than in summer (dry season). [What light levels are incident on vertical leaves?]

page 44. During the past summer, I was lucky enough to be able to work with the famous Professor Olle Björkman of the Carnegie Institution of Washington, measuring photosynthesis rates on plants under natural conditions in the field. The very sophisticated instruments in his mobile laboratory allowed me to measure photosynthesis rates under very carefully controlled conditions, even though all measurements were taking place in the field. Using instruments in his mobile laboratory, I measured net photosynthesis in *Encelia farinosa* under two levels of soil water availability: well-watered and water-stressed. The data that I obtained follow. Photosynthesis was measured as net carbon dioxide uptake in $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$. Photon flux density was measured in $\mu\text{mol photons m}^{-2} \text{ s}^{-1}$. Leaf temperature was measured in degrees Celsius. Ambient CO_2 (c_a) was 377 ppm and intercellular CO_2 (c_i) concentrations were measured in ppm. Variations in c_i concentrations from the naturally occurring value were created by introducing the plant into an environment where atmospheric CO_2 varied and other environmental parameters were held constant.

Experimental treatment 1

| Data point # | Net photosynthesis, $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ | Leaf temperature, $^{\circ}\text{C}$ | Intercellular CO_2 , ppm | Photon flux, $\mu\text{mol m}^{-2} \text{ s}^{-1}$ |
|--------------|--|--------------------------------------|-----------------------------------|--|
| 1 | 5.2 | 30 | 78 | 2,000 |
| 2 | 24.5 | 29 | 155 | 2,000 |
| 3 | 35.0 | 30 | 200 | 2,000 |
| 4 | 43.3 | 30 | 264 | 2,000 |
| 5 | 53.4 | 29 | 444 | 2,000 |
| 6 | 55.6 | 30 | 634 | 2,000 |
| 7 | 55.7 | 30 | 755 | 2,000 |

Experimental treatment 2

| Data point # | Net photosynthesis, $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ | Leaf temperature, $^{\circ}\text{C}$ | Intercellular CO_2 , ppm | Photon flux, $\mu\text{mol m}^{-2} \text{ s}^{-1}$ |
|--------------|--|--------------------------------------|-----------------------------------|--|
| 1 | 3.2 | 30 | 78 | 2,000 |
| 2 | 14.7 | 29 | 155 | 2,000 |
| 3 | 21.0 | 30 | 200 | 2,000 |
| 4 | 26.0 | 30 | 264 | 2,000 |
| 5 | 32.0 | 29 | 444 | 2,000 |
| 6 | 33.4 | 30 | 634 | 2,000 |
| 7 | 33.4 | 30 | 755 | 2,000 |

In experiment 1, in which plants were well-watered, the leaf conductance was $0.7 \text{ mol m}^{-2} \text{ s}^{-1}$. In contrast, in plants grown under water stress (experiment 2), the leaf conductance was to $0.4 \text{ mol m}^{-2} \text{ s}^{-1}$. Of immense interest to me, I noticed that the c_i/c_a ratios remained nearly constant at 0.7 between the two growth regime treatments.

10 (10). Stomata impose a diffusion barrier, resulting in a steep decrease in CO_2 concentrations inside the leaf compared to the outside atmosphere. What is the intercellular carbon dioxide concentration in leaves under both well-watered and drought conditions under ambient atmospheric carbon dioxide levels?

(10) 264 ppm

12 (10). Why does the photosynthetic rate saturate at high intercellular carbon dioxide concentrations?

(8) Photosynthesis saturates at high light because a resource other than carbon dioxide becomes limiting.

(2)The limiting resource that causes the response curve to saturate is photon flux (limits RuBP regeneration).

13 (10). Is the slope of the dependence of net photosynthesis HIGHER or LOWER for plants grown under water stress conditions? Answer and then provide an explanation for why this slope difference exists.

(5) Lower.

(5) The slope of the response curve is dependent on protein levels, specifically proteins associated with the dark reactions to photosynthesis. Under water stress, plants partly close stomata and acclimate to reduced carbon dioxide supply by reducing photosynthetic capacity.

BONUS, 10 points.

page 231. Last year I tried to repeat a number of classic plant ecology studies focusing on nutrients and plant growth in the Intermountain West. My students and I grew *Artemisia tridentata*, *Astragalus utahensis*, and *Acer grandidentatum* from seed for an entire year. One of the students was sensitive to infections and so we sterilized the sandy soils to avoid the potential for his getting sick. Another student was sensitive to hayfever and so we terminated the experiment before plants could flower. To allow for natural plant-microbial interactions, some of the seeds were sprayed with *Rhizobium* and/or mycorrhizal fungal spores. Different treatments existed, including high and low water treatment levels, full sunlight versus half-shade, and nitrogen and/or phosphorus. Plants biomass (grams per plant) was measured at the end of the experiment. Roots were excavated and examined for the presence of root nodules as indicators of nitrogen fixation. Below are some of the data for *Acer grandidentatum*.

| Treatment | | | | | Observation |
|-------------------------------------|--|-------------------------------|----------------------------------|--------------------------------|-------------------------|
| Seeds sprayed with <i>Rhizobium</i> | Seeds sprayed with various fungal spores | Well-watered (watered weekly) | Phosphorus fertilizer added once | Nitrogen fertilizer added once | Total plant biomass (g) |
| + | - | + | + | + | 65 g |
| + | + | + | - | + | 45 g |
| - | + | + | + | + | 55 g |
| - | - | + | - | + | 12 g |

Unfortunately, the student was late in turning in his data. I finally got the total plant biomass values today: 65 g, 12 g, 55 g, and 45 g. Then, I realized that the student had forgotten to tell which total plant biomass values were associated with each treatment above.

What is the correct ranking of observed biomasses, going from top to bottom in the last column? Enter the correct numbers into the blank spaces on the table above.

4 points answer 1

1 point answer 2

1 point answer 3

4 points answer 4