C_3/C_4 Plant Models and Climate Change Sustainability Activity – Plant Responses

Pre-lab Addition:

In addition to hormones and tropisms, plants have also evolved in response to their environment. One example of this can be observed in the evolution of C_4 plants.

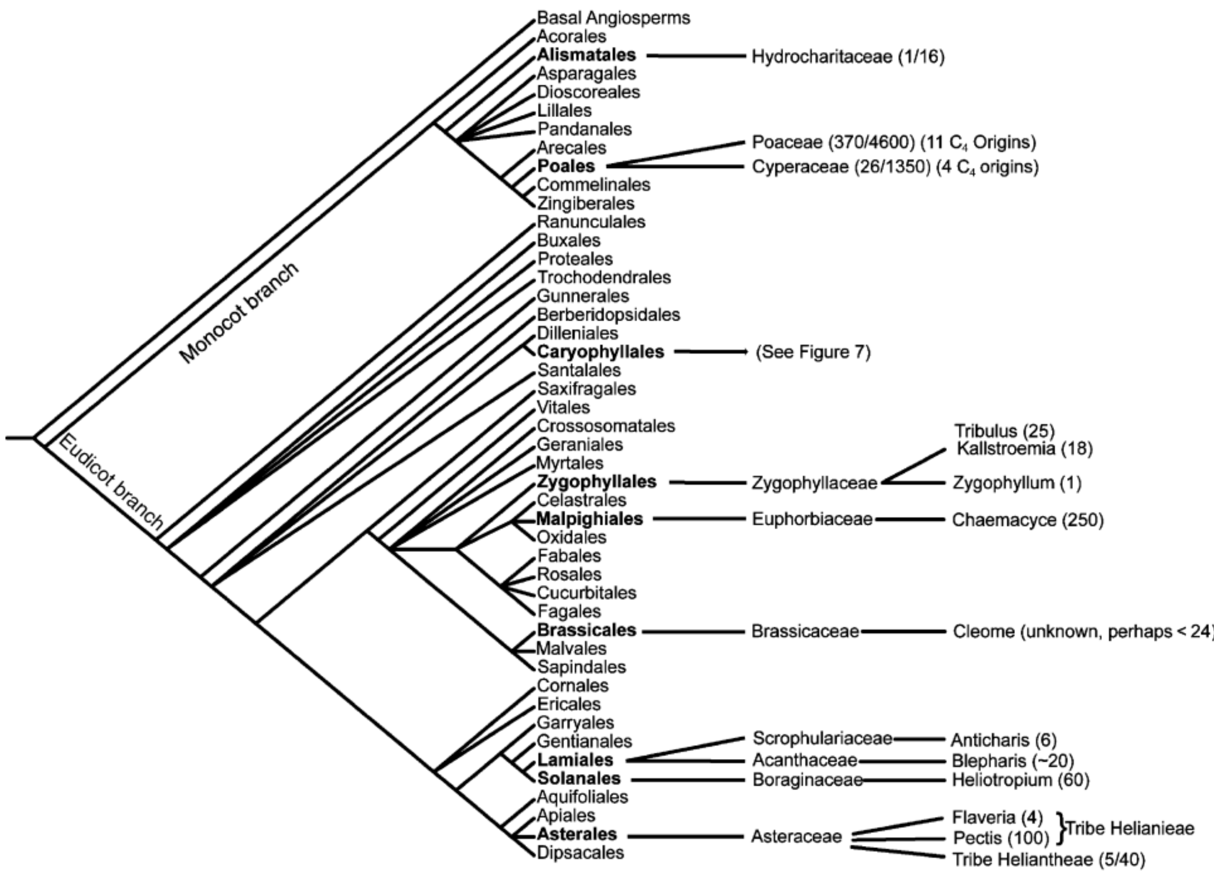
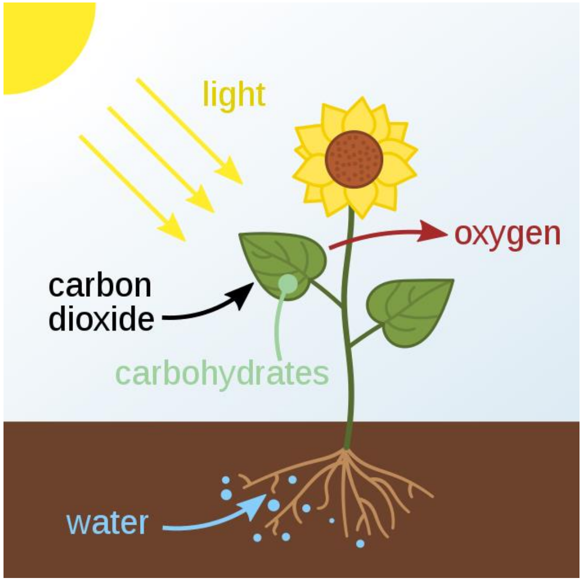


Fig. 5 Distribution of C_4 photosynthesis in the taxonomic orders of the angiosperms. Angiosperm orders with C_4 photosynthesis are shown in bold. Lines to the right of these orders indicate families and principal C_4 genera within a lineage. Numbers in parentheses refer to estimates of genera/species numbers or, where relevant, just species numbers. Adapted from Stevens (2003) by permission.

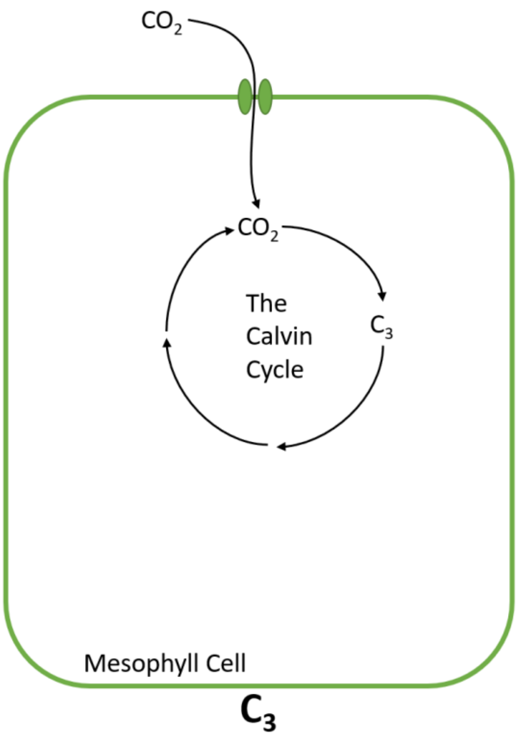
The evolution of C_4 plants in angiosperms, taken from *The evolution of C_4 photosynthesis* (https://doi.org/10.1111/j.1469-8137.2004.00974.x) (2004) by Rowan F. Sage.

Up until now we have described photosynthesis as one process that all plants complete. While all plants do photosynthesis, there are actually two different routes they could take.



The products and required materials of photosynthesis are the same for both photosynthetic processes.

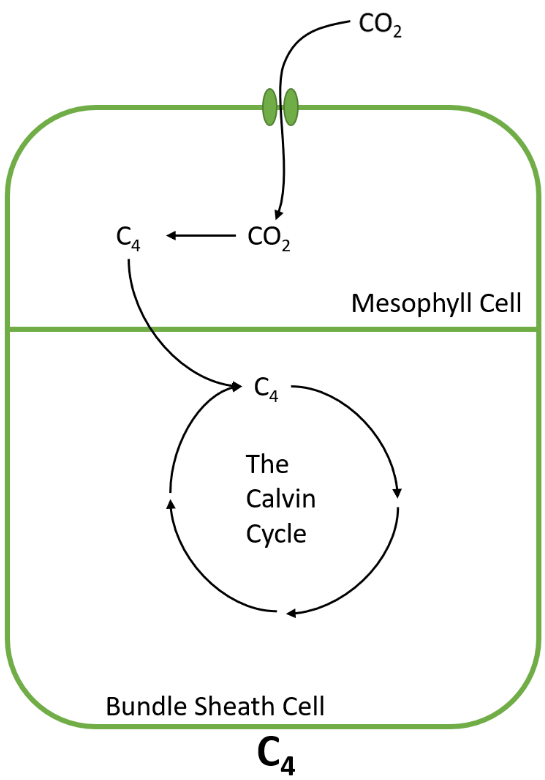
The first photosynthetic pathway is seen in C_3 plants, where carbon dioxide molecules brought in from the stomata are used to create sugars through photosynthesis directly in the mesophyll cells of the leaf. During this process, the carbon dioxide binds to an enzyme, rubisco, that changes it into a three carbon molecule. This is why these plants are called C_3 plants. Most plants are C_3 plants, but some specific examples are soybeans, cotton, and cereal grains like oats and rye.



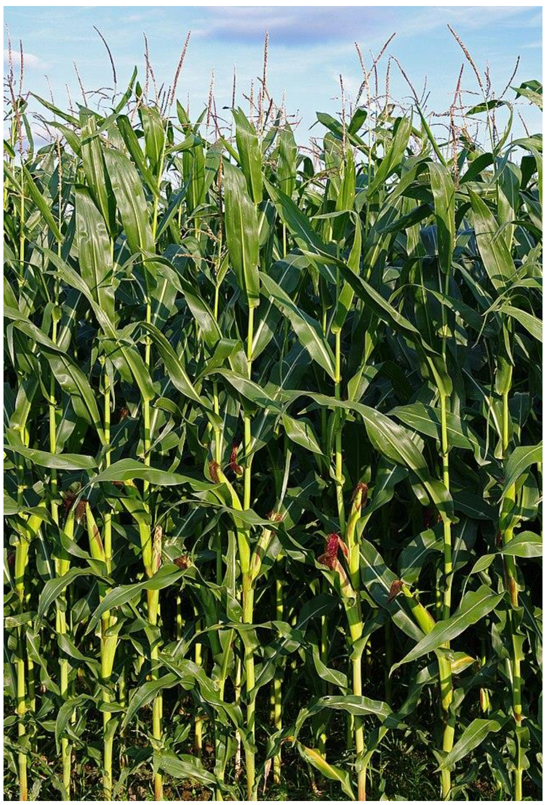
The C_3 plant photosynthetic pathway.

Bamboo is a C_3 plant.

The second photosynthetic pathway occurs in C_4 plants, where carbon dioxide is stored in the mesophyll cells as a four carbon molecule and then transported into the bundle sheath cells where it reacts with rubisco for photosynthesis. In addition, some C_4 plants living in hot, dry climates have further evolved to do gas exchange during the night and complete photosynthesis in the day (referred to as CAM plants) to reduce water loss. Only a few plants have evolved to perform the C_4 photosynthetic pathway, and the ones that have evolved this trait all evolved it separately. This process is called **convergent evolutions** (https://en.wikipedia.org/wiki/Convergent_evolution). Some examples are sugar cane, cactus, pineapple and corn.

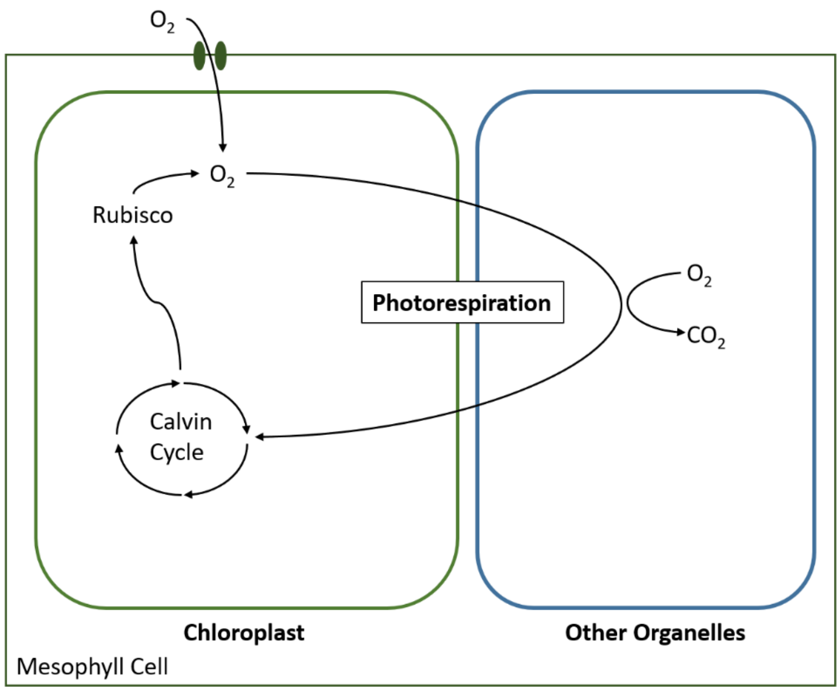


The C_4 plant photosynthetic pathway.



Corn is an example of a C_4 plant.

Now, you may be asking why plants have evolved two different photosynthetic pathways…The answer is that they have made adaptations to their environments! As you have learned previously, open stomata also allow the exchange of carbon dioxide, oxygen and water. In areas with warmer temperatures, water will evaporate faster, causing the stomata to stay open for a shorter amount of time. This leads to a buildup of oxygen in the leaf tissue. In C_3 plants, this causes rubisco to bind to oxygen instead of carbon dioxide causing the plant to go through the process of photorespiration instead of photosynthesis. **Photorespiration** is a cascade of events that leads to a net loss of carbon in plants instead of producing glucose. Therefore, plants need to avoid this at all costs.



Photorespiration leads to loss of carbon in the form of carbon dioxide!

Now, this is where the C_4 pathway comes in. C_4 plants separate where they store carbon dioxide and oxygen brought in through the stomata and where rubisco reacts with the carbon molecules for photosynthesis. This reduces how often rubisco binds to oxygen.

In this lab, you will learn how and why plants respond to external and internal stimuli. In addition, you will learn how environmental factors have shaped evolution in plants, and how current unsustainable practices have led to a unique problem within plants.

Activity:

Part IV: C3/C4 Photosynthesis

Recall that the evolution of C_4 plants resulted from plant's need to respond and adapt to their environment. Of course, while the rest of these responses happen within a plant's lifetime, evolution occurs over several generations. This means that the evolution of C_4 plants is a culmination of responses to the environment from several generations of plants that resulted in genetic and physical changes.

All plants evolved from early lands plants, much like C_4 plants evolved from C_3 plants. These fossils are of early lands plants.

In the following activity, you will work with your group to determine how both types of plants (C_3/C_4) are handling living in our ever changing environment and how their responses may affect the biodiversity of plants in the future. You will be doing this by using models of C_3 and C_4 plants. Models (both computerized and physical) are often used in science to test hypotheses when researchers are unable to use the real thing. In today's activity, you will use these models to test how C_3 and C_4 plants are responding to climate change.

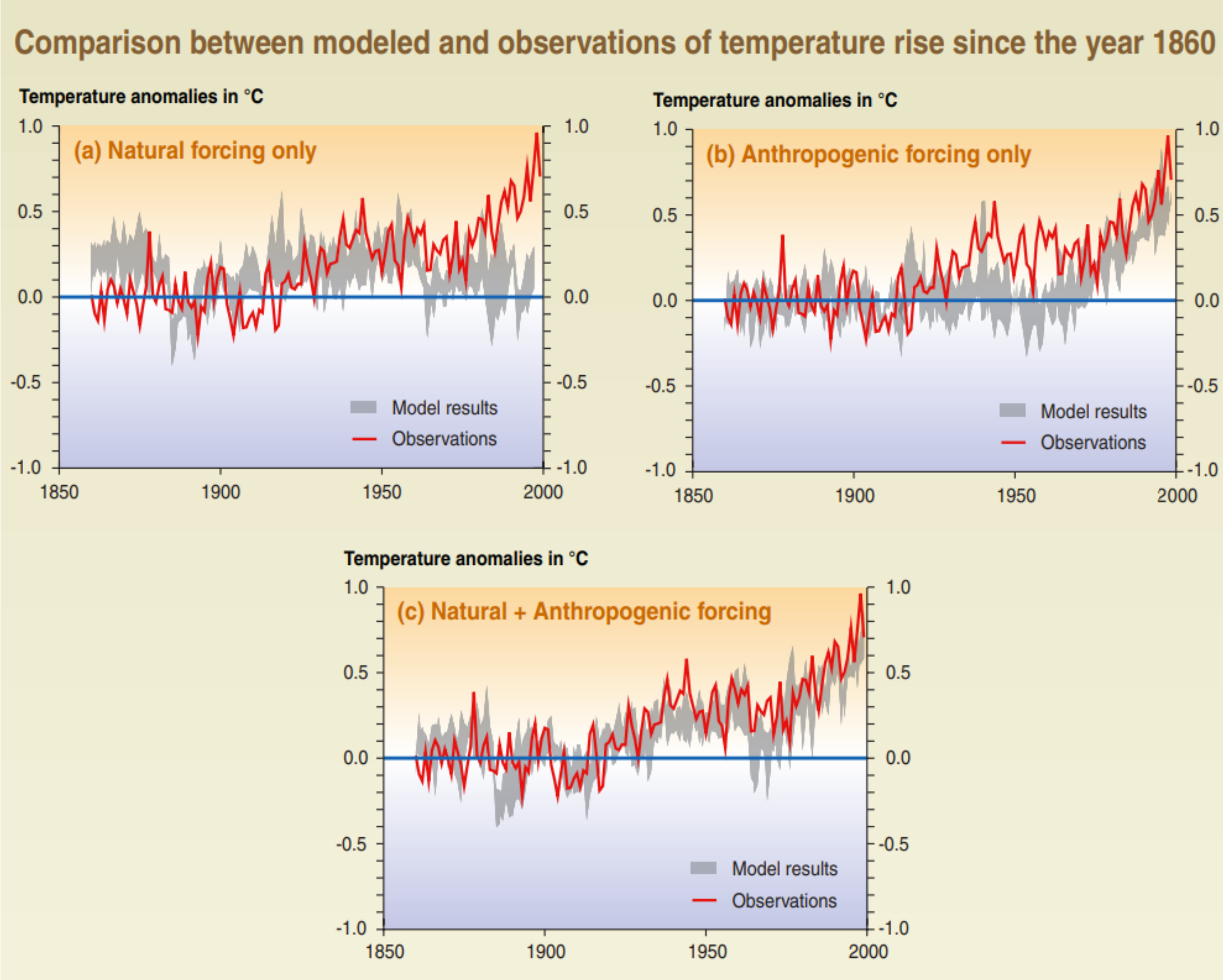


Figure SPM-2: Simulating the Earth's temperature variations (°C) and comparing the results to the measured changes can provide insight to the underlying causes of the major changes. A climate model can be used to simulate the temperature changes that occur from both natural and anthropogenic causes. The simulations represented by the band in (a) were done with only natural forcings: solar variation and volcanic activity. Those encompassed by the band in (b) were done with anthropogenic forcings: greenhouse gases and an estimate of sulfate aerosols. And those encompassed by the band in (c) were done with both natural and anthropogenic forcings included. From (b), it can be seen that the inclusion of anthropogenic forcings provides a plausible explanation for a substantial part of the observed temperature changes over the past century, but the best match with observations is obtained in (c) when both natural and anthropogenic factors are included. These results show that the forcings included are sufficient to explain the observed changes, but do not exclude the possibility that other forcings may also have contributed.

Q2 Figure 2-4

Modeled and recorder differences in temperature from the Climate Change 2001: Synthesis Report - International Panel on Climate Change (2001) (https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_TAR_full_report.pdf).

Climate change refers to the changing of climate due to atmospheric shifts, usually related to increased levels of carbon dioxide. Often, this increase in carbon dioxide coincides with an increase in temperature. **Based on what you have learned from the prelab, develop a hypothesis with your group as to which type of plant C_3 or C_4, will produce more glucose in warmer temperatures.**

Now that you have come up with a hypothesis, it is time to test it! Within your group, decide who wants to play the following roles:

Timekeeper	This person maintains a watchful eye on the timer to make sure the CO_2 master does not go over the allotted time.
Data Recorder	This person records how much CO_2 is converted into glucose after each day.
CO_2 Master	This person is responsible for putting as much CO_2 into the plant during the timeframe.
Chloroplast Overlord	This person is in charge of exchanging the CO_2 into glucose and calculating how much O_2 will bind to rubisco at the end of each day.

You will complete this simulation with the group next to you at your lab table. Decide which team wants to be the C_3 plant, and which team wants to be the C_4 plant. Then, read the directions to prepare for your simulation.

Each day, draw a card to determine the environment your plants are in and how long their stomata stay open. Then, once both teams are ready, flip open the timer of the time on the card and race to see which plant produces more glucose at the end of the day!

The objective of this simulation is to get as many CO_2 molecules (the round chips labeled with CO_2) into the plant as possible within the time limit. At the end of each day, the Chloroplast Overlord determine how much glucose was produced through photosynthesis during that day, which will then be recorded by the data recorder. The conversion rate is as follows:

C_3 plants: 6 CO_2 molecules make 1 glucose.
C_4 plants: 8 CO_2 molecules make 1 glucose.

But wait, there is a catch! On certain days, rubisco in C_3 plants will bind to O_2 instead of glucose. This means you will lose glucose (energy) due to photorespiration! Roll the specified ‘energy dice’ on these days (on the cards) to see how much glucose is lost in **ONLY** C3 plants.

Once you are ready, have one person from each team roll the 2-4 dice to determine which team will draw the first card (highest roll goes first). Then, rotate drawing cards until you have completed a week's worth of photosynthesis (7 cards total).

On playing cards:
Card 1: Today is a pleasant 68°F, therefore both plants' stomata stay open for 5 minutes.

Card 2: Today is a pleasant 70°F, therefore, both plants’ stomata stay open for 5 minutes.

Card 3: Today is a pleasant 73°F, but it is very windy outside. Both plants' stomata stay open for 3 minutes.

Card 4: Today is a pleasant 75°F with a slight breeze. Both plants' stomata stay open for 3 minutes.

Card 5: Today is a pleasant 64°F, but you are under a drought! Both plants' stomata stay open for 2 minutes.

Card 6: Today is a warm 80°F. The C4 plant's stomata stay open for 5 minutes, but the C3 stomata can only stay open for 3 minutes.

Card 7: Today is a warm 86°F. The C4 plant stomata stay open for 5 minutes, but the C3 stomata can only stay open for 3 minutes.

***Oh No!** Rubisco in the C3 plant also mistakenly bonded to oxygen! Roll the 1-2 dice to see how much glucose was lost.

Card 8: Today is a warm 77°F but it's a bit breezy. The C4 plant's stomata stay open for 3 minutes, but the C3 stomata can only stay open for 2 minutes.

Card 9: Today is a warm 79°F. The C4 plant stomata stay open for 5 minutes, but the C3 stomata can only stay open for 3 minutes.

Card 10: Today is a warm 87°F and you are experiencing a drought!. The C4 plant's stomata stay open for 2 minutes, but the C3 stomata can only stay open for 1 minute.

***Oh No!** Rubisco in the C3 plant also mistakenly bonded to oxygen! Roll the 1-2 dice to see how much glucose was lost!

Card 11: Today is a hot 90°F. The C4 plant's stomata stay open for 5 minutes, but the C3 stomata can only stay open for 3 minutes.

***Oh No!** Rubisco in the C3 plant also mistakenly bonded to oxygen! Roll the 1-2 dice to see how much glucose was lost!

Card 12: Today is a hot 92°F. The C4 plant's stomata stay open for 3 minutes, but the C3 stomata can only stay open for 2 minutes.

***Oh No!** Rubisco in the C3 plant also mistakenly bonded to oxygen! Roll the 1-2 dice to see how much glucose was lost!

Card 13: Today is a hot 95°F and it's very windy. The C4 plant's stomata stay open for 2 minutes, but the C3 stomata can only stay open for 1 minute.

***Oh No!** Rubisco in the C3 plant also mistakenly bonded to oxygen! Roll the 2-4 dice to see how much glucose was lost!

Card 14: Today is a hot 94°F and you are experiencing a drought. The C4 plant stomata stay open for 2 minutes, but the C3 stomata can only stay open for 30 seconds to conserve water.

***Oh No!** Rubisco in the C3 plant also mistakenly bonded to oxygen! Roll the 2-4 dice to see how much glucose was lost!

Card 15: Today is a blistering 103°F. The C4 plant stomata stay open for 1 minute, but the C3 stomata can only stay open for 30 seconds to conserve water.

***Oh No!** Rubisco in the C3 plant also mistakenly bonded to oxygen! Roll the 2-4 dice to see how much glucose was lost.

Once you have finished with your simulation, graph your data putting glucose production on the y-axis and temperature on the x-axis. Make sure to include both the C_3 and C_4 plant data.
Afterwards, answer the following questions:

- Did your results support your hypothesis? If so, explain how. If not, explain why this might be.
- Which plant had the most efficient photosynthetic pathway in mild temperatures (65°F-75°F)? Use your results to support your answer.
- Which plant had the most efficient photosynthetic pathway in hot temperatures (75°F-100°F)? Use your results to support your answer.

The following graph is from *Comparative ecophysiology of C3 and C4 plants* by Pearcy and Ehleringer (1987). (https://doi-org.ezproxy2.library.colostate.edu/10.1111/j.1365-3040.1984.tb01194.x) This paper reviews the differences in physiology in C_3 and C_4 plants due to the environment.

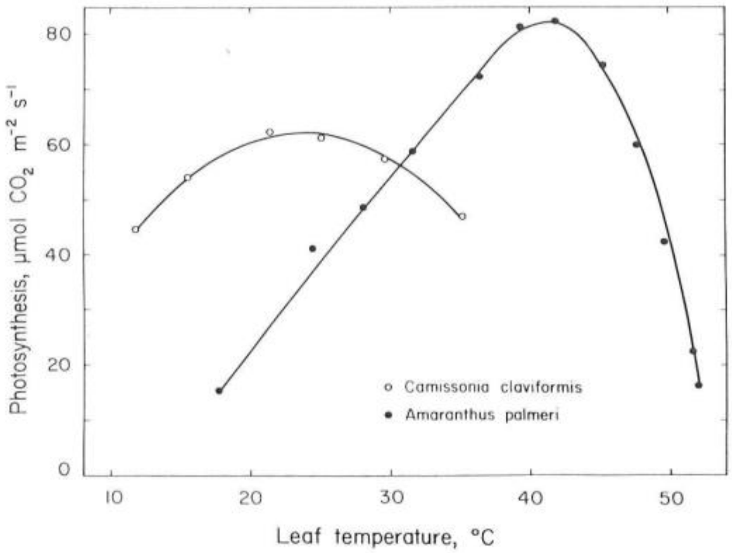


Figure 10. Response of photosynthesis to leaf temperature in the winter active C_3 desert ephemeral *Camissonia claviformis* and the summer active C_4 desert ephemeral *Amaranthus palmeri*. Data are redrawn from Mooney *et al.* (1976a) and Ehleringer (1983).

Interpret this graph and discuss the questions below with your group:

- Compare your graph to the graph above. Does your data follow similar trends? Why or why not?
- Predict how climate change affects both types of plants.
- Based on your simulation and the graph above, predict how climate change may affect plant biodiversity in the future. How might this affect future food availability?

When you are finished, make sure to check in with your TA about the answers to the questions about the graphs.

Post Lab Question:

Food staples (https://en.wikipedia.org/wiki/Staple_food) are foods that make up a large portion of a population's diet. Some examples of this would be corn, sugarcane, wheat, and oats. Corn and sugarcane are both examples of C4 plants, while wheat and oats are examples of C3 plants. Based on what you learned in the lab, how do you think both types of plants will be affected by increasing temperatures, and how may this affect food availability in the future? Also, what do you think may be a possible solution for this problem?

[0.5 pt for how C3 plants are affected by climate change; 0.5 pt for how C4 plants are affected by climate change; 0.5 pt for a possible solution, and 0.5 pt for a clear and concise answer.]