Photosynthetic Environment

Plants do not use all the light that illuminates them

Our local star, the sun, shines light outwards from the fusion reactions that are occurring in the sun. This light passes through the solar system. The side of the Earth facing the sun is bathed in this light; the other side of the earth is in its night period. The sun shining on the Earth passes through the atmosphere; of course some energy is lost. Depending on how much atmosphere the light passes through and depending on the quality of that atmosphere, a certain amount of light shines upon an outdoor plant. Of the light that strikes a plant, only a small amount is actually converted into bond energy in carbohydrates. The rest is lost by the plant for the various reasons shown here.

As you know light is a waveform which can be measured in terms of wavelength. Our brains interpret electrical signals from different wavelengths of light perceived by the eye as different colors. The range of human vision (400 to 700 nm wavelengths) in terms of wavelength is called the visible spectrum. Plants use light waves differentially; some wavelengths are useful for photosynthesis, others are less-so. The destiny of light waves of different wavelengths is shown below.
You can see from this diagram that wavelengths from 400 to 700 nm are photosynthetically active radiation (PAR). Photometers are calibrated over this range of wavelengths and light values in experiments are generally calibrated as PAR light. Light above 700 is relatively inactive in photosynthesis...I think you know why! The greenish portions of this figure show the wavelengths that are reflected (top) or transmitted (below).

**Plants compete for light**

A plant that is in the environment with other plants is in competition for available light. Species that can grow quickly will overtop poorer competitors and shade them out. This relationship is demonstrated below.
As you might notice, the PAR light illuminating the canopy plants is high, but the light that penetrates the canopy to reach understory plants is far lower. Wavelengths beyond 700nm certainly penetrate the canopy, but are of such low energy that they cannot be used for photosynthesis by plants on the forest floor. It is no surprise that forest floor plants in Connecticut are early to sprout in the spring and get their reproduction essentially done before the canopy trees leaf out!

**Plants can do more photosynthesis in bright light**

It is no surprise that plants grow better when more light is available, because photosynthesis can provide more carbohydrate in brighter light. This relationship is shown below. This is a standard light-dose response curve. It is not unlike the one you generated in class from the leaf in the cuvette with the oxygen electrode.
You might notice that this curve is different from the one you produced in class. You measured oxygen production, this figure shows measurements of carbon dioxide uptake. This difference is important in many ways but also insignificant too. Your oxygen measurements should have produced a similar plot with essentially all the same relationships. The curve has a negative y-intercept which represents the rate of respiration...it is negative because respiration gives-off carbon dioxide rather than using it. The x-intercept on this curve shows the intensity at which photosynthetic use of carbon dioxide is balancing the release of carbon dioxide by respiration. This point is called the light compensation point. A plant is basically maintaining itself at this intensity of light and cannot grow, reproduce, or defend itself very well against herbivores. At intensities of light above this compensation point (about 100 µmol m\(^{-2}\) sec\(^{-1}\)) the plant can add to its reserves, grow, and reproduce. At intensities below the compensation point, the plant is using its reserves and will die when those are exhausted. The curve shows saturation kinetics (a leveling-off curve). At lower light intensities, the increases in light give strong increases in photosynthesis. At higher light intensities, providing additional light does not increase photosynthesis as much. That is because some other factor (probably carbon dioxide availability) is limiting to the process.

Light responses are species-specific
Plants do not respond to light equally. Some species are more efficient in light use than are others:

I think you can see that *Atriplex* is a sun plant in that it has a higher compensation point (look closely). It takes more light to drive a sun plant. The *Asarum caudatum* is a shade-tolerant plant with a lower compensation point (actually just above 0...hmmm?). You can also see that the carbon dioxide uptake is higher for the sun plant than for the shade plant too at saturating light intensities.

**Plants can adapt their photosynthetic dynamics to their environment**

Our next figure shows how one plant *Atriplex triangularis* can adjust its growth kinetics to differing environments. Grown in the shade it acts like a shade-tolerant plant, grown in the sun in acts like a sun plant.
Plants are also prepared to deal with changes in photon flux. You can see in the diagram below, sun plants have evolved to adjust to light intensity.
While individual needles show typical saturation kinetics, the shoot as a whole of a single individual, and the canopy of a population as a whole, are capable of increasing photosynthesis without saturation. This has to do with the three-dimensional arrangements of leaves on the shoot and trees. As more light hits the shoot or canopy, it penetrates to needles that are in the shade and their photosynthesis contributes to ever-more photosynthetic capacity.

Shade plants typically have all their leaves in a single layer, however, and so they show saturation kinetics:
The excess light shown above the response curve can be damaging to a shade plant and indeed many shade plants are intolerant of direct sun. So sometimes the leveling-off saturation kinetics actually may show decay of rate at higher intensities of light.

Plants must deal with heat

Plants cannot go hide under a rock or walk to the nearest shade tree and "hide" so they have to manage heat loads because the grow immotile in the light. The diagram below shows the heat-balance problem:
Light hits the leaf and some of it is changed to longer wavelengths and escapes as heat. Some of the energy heats the leaf but the leaf conducts that heat to the nearby air. Most of the absorbed heat, however, is lost by evaporative cooling by the transpiration stream. Under excessive light evaporative cooling is going to have to keep the leaf from "cooking."

**Plants must respond to changes in carbon dioxide availability**

Plants need to adapt to changing values of critical variables such as carbon dioxide availability. While we often think of the global atmosphere as pretty constant in terms of gas composition, as a matter of fact studies of gases trapped in ancient ice show us that changes in carbon dioxide availability have occurred:
Obviously the current release of carbon dioxide from human activity is altering gas composition strongly. Plant growth may be accelerated due to this human activity.

But carbon dioxide availability relates to our previous discussion of Calvin cycle, C₄ cycle, and CAM plants as well. The plants that use PEPcarboxylase as the fixation enzyme can much more efficiently use carbon dioxide:

Clearly the C₄ plant is much better at trapping carbon dioxide at lower concentrations...this is reflecting PEPcarboxylase activity and reduction of photorespiration. The C₃ plant is better at higher concentrations of carbon dioxide reflecting the extra ATP needed to drive the C₄ cycle. The ATP becomes more limiting when carbon dioxide is less limiting.
CAM plants respond in their own unique way shown here:

You can see that guard cells close in the daytime, and drag down with them the carbon intake and water loss. At night, the guard cells open the stoma and carbon can be taken in at the expense of some water loss. Of course some water loss is needed to bring in more soil minerals, but these desert plants are obviously well adapted to minimizing water losses during the heat of the day.

**Plants respond to temperature**

Photosynthesis reactions are of two types: enzymatic (Calvin cycle) and electronic (light reactions). The enzymatic steps are very temperature sensitive...the electronic ones are less-temperature sensitive, but may appear to be because of their dependency upon enzymatic steps:
The availability of carbon dioxide changes with temperature too, so this graph shows how plants are less responsive to temperature under "normal" conditions than they are when much carbon dioxide is available.

The availability of carbon dioxide changing with temperature impacts the balance of Calvin cycle activity and photorespiration as shown below:
As temperature rises and carbon dioxide becomes less available, the quantum efficiency of photosynthesis decreases in C3 plants. This problem is not shown in the C4 plant.

Obviously then plants are adapted to different environments. Where water and carbon dioxide are plentiful, C3 plants are good competitors. Where carbon dioxide is limiting and temperatures are warmer, C4 plants are good competitors. Where carbon dioxide is limiting, temperature is hot, and water is limiting (deserts), CAM plants are good competitors. As one analyzes the species composition of plant groups on Earth, these generalizations appear to be well-justified.