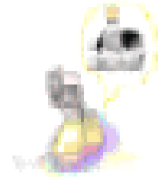
UNIT 1: METABOLIC PROCESSES



E. Photosynthesis and the Environment

Environmental Factors That Influence Photosynthesis

There are a lot of environmental factors that may influence photosynthetic rates in autotrophic organisms. The most obvious ones are light, CO_2 concentration, and temperature. Like any chemical reaction, the rate of photosynthesis can be measured a number of different ways. One can look at the rate of reaction consumption, or the rate at which the product is created. Therefore, measuring the rate of CO_2 consumption, or the rate of O_2 evolution are equally effective methods to determine how fast photosynthesis is occurring. It is important to note that gas exchange (CO_2 for O_2) occurring in plants involves three processes:

Net CO_2 uptake = photosynthetic CO_2 uptake -- photorespiratory CO_2 evolution -- respiratory CO_2 evolution

Net O_2 evolution = photosynthetic O_2 evolution -- photorespiratory O_2 uptake -- respiratory O_2 uptake

Light Intensity, CO_2 and Photosynthesis

Just as the weakest link of any sports team is the factor that determines its success, the slowest step of any series of reaction mechanisms will determine the over all rate of the entire process. Photosynthesis takes place in two major parts: ATP and NADPH production (light reactions) and carbon fixation ("dark" reactions). Figure 3, p. 174 illustrates the two major parts of the entire photosynthetic process. Both processes are dependent upon each other – the relative concentrations of NADPH and ATP due to their consumption in the Calvin cycle influences photosystem mechanisms, and the amount of ATP and NADPH produced in the light reactions dictates how fast CO_2 is fixed in the Calvin cycle. If any one of these two parts slows down, the entire photosynthetic process is affected, which ultimately affects both the net CO_2 uptake and the net O_2 evolution. Figure 2, p. 173 demonstrates the relationship between light intensity and the rate of net CO_2 uptake. At fixed levels of CO_2 concentration (330 ppm), and at a fixed temperature, light intensity does affect the rate of photosynthesis as seen in Figure 2, p. 173. At no light intensity (complete darkness), the plant is producing more CO_2 than it is consuming – respiration rates are faster than photosynthetic rates. This is why the net uptake is negative. At the net CO_2 uptake of zero the rate of CO_2 evolution due to both respiration and photorespiration <u>equals</u> the rate of CO_2 consumption due to photosynthesis. The light intensity that results in a zero net CO_2 uptake is called the **light compensation point**. Above this intensity, the rate of photosynthesis increases at a steady rate. The relationship will continue to be linear as long as there is a sufficient amount of CO_2 to be fixed by the Calvin cycle enzymes to support the surplus ATP and NADPH made by increasing irradiance. At relatively low light intensities the rate of consumption of ATP and NADPH in the dark reactions, far exceed their surplus production due to the greater number of photosystems being activated by increased irradiance. This means that Figure 3(b) is moving at a faster rate than Figure 3(a), p. 174. When the light intensity reaches very high levels, and all photosystems are operating at maximum capacity, the maximum amount of ATP and NADPH are being produced. The over all rate of CO_2 production will depend on whether or not the plant has enough CO_2 to be fixed by the Calvin cycles to support the surplus ATP and NADPH. When all the Calvin cycles are working, any increase in light intensity does not affect photosynthetic rates. The irradiance level at which this occurs is called the **light-saturation point**. This can be seen at relatively high light intensities. This means that Figure 3(a) is moving faster than Figure 3(b), p. 174. Therefore, at low light intensities, photosynthesis rates are light limited, whereas at high light intensities, photosynthetic rates are CO_2 limited. By increasing CO_2 concentrations, the light saturation point of any plant can be increased. However, when all the rubisco molecules that the plant possesses are working at maximum enzyme-substrate capacity, the light-saturation point is once again reached. Figure 4, p. 174 illustrates this concept. The concentration of CO_2 at this point is called the **carbon dioxide compensation point**. This is when all the rubisco active sites are occupied by CO_2, and the enzyme is **substrate saturated**.

Temperature and Photosynthesis

Any chemical reaction will occur faster at higher temperatures. Higher temperatures give reactant molecules higher kinetic energy. When molecules move faster, they collide more frequently. This means that there is a greater probability of collisions between reactant molecules, which results in more frequently-occurring products. However, biochemical reactions have temperature limits since most of them are enzyme driven. When temperatures are too high, enzymes become denatured and are inactive. As long as temperature increases are within tolerable limits, photosynthetic rates will increase. Figure 7 (a), p. 175, shows the light-response curve for a typical C_3 plant at 10ºC and 25ºC. At relatively low light intensities, the initial slope of the curve is greater at 10ºC. C_3 plants take up CO_2 more efficiently at 10ºC because less photorespiration occurs than what would occur at 25ºC. At greater light intensities, the light-compensation point is higher at 25ºC than it is at 10ºC. This is because the Calvin reactions are sped up by the increased temperature, and are no longer the limiting factor in the over all process, as they are at 10ºC. By increasing the temperature to 25ºC, Calvin organic acids were given more kinetic energy, thus increasing the rate of carbon fixation (i.e. rubisco action).

Oxygen and Photosynthesis

The over all photosynthetic process is decreased by higher oxygen concentrations. This is because at high levels, oxygen behaves like a competitive inhibitor on the rubisco active site. Since rubisco binds more to oxygen than to carbon dioxide, photorespiration occurs instead of photosynthesis. Figure 6, p. 175 shows the relationship between the rate of photosynthesis and ambient oxygen concentration.

C_3 vs. C_4/CAM Photosynthesis

Above 25ºC, C_4/CAM plants exhibit higher photosynthetic rates than C_3 plants. Below 25ºC, C_3 plants possess a higher carboxylation efficiency. This is because at temperatures above 25ºC, plant stomata close to prevent water loss, thereby reducing the CO_2 concentration in the leaf. When this occurs, oxygen levels increase to higher than normal levels, resulting in the competitive inhibition of rubisco. Photorespiration then occurs which consumes Calvin acids and reduces CO_2 fixing. C_4/CAM plants have the ability, via PEPc, to trap CO_2 into precursor acids, and then release it to the Calvin cycle. Below 25ºC, water loss is not a problem for C_3 plants and the stomata remain open. This increases CO_2 concentrations in the C_3 leaf, which activates and increases rubisco activity. C_4 plants fix CO_2 at a constant rate, despite increases in temperature and increases in CO_2 concentration. Figure 7 (b), p. 175 illustrates these relationships. This is why corn, a C_4 plant, grows best during hot summers. It also explains why Kentucky bluegrass, a C_3 plant, is out competed by crabgrass and weeds (C_4 plants) during hot, dry summers.

Sun Plants vs. Shade Plants

Shade plants possess leaves that are thinner, broader, and greener (more chlorophyll-containing), than the leaves of a sun plant. By possessing more chlorophyll, and broader leaves shade plants increase their light absorption ability, which makes them fix CO_2 more efficiently at low light intensities (see Figure 10, p. 177). As well, shade plants have lower respiratory rates than sun plants, which is an adaptation that allows them to survive in light-limited conditions. The light-saturation point is higher for sun plants than it is for shade plants. This is because sun plants possess more Calvin acids and more rubisco than shade plants, therefore can use up the extra ATP and NADPH faster than they are being produced.

Homework: 1-9, p. 178